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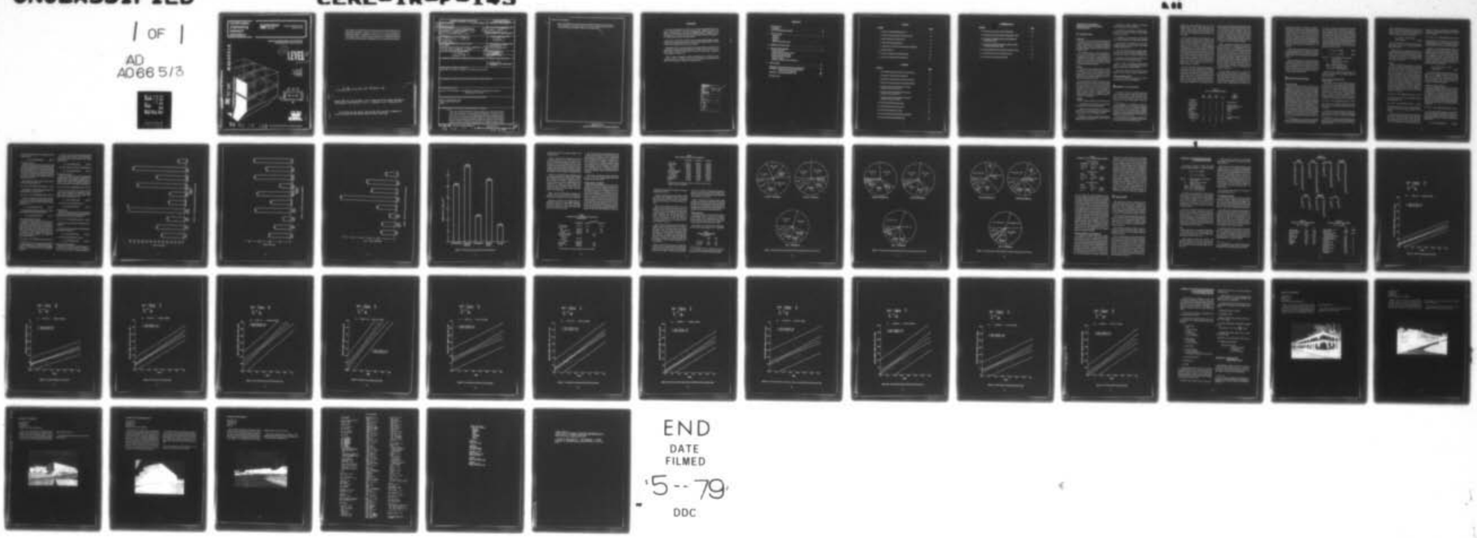

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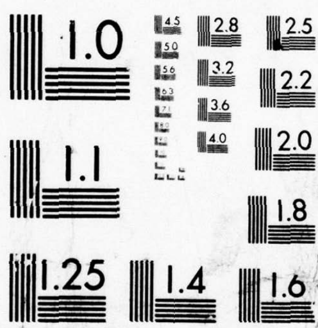

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INTERIM REPORT E-143
February 1979

FIXED FACILITIES ENERGY CONSUMPTION INVESTIGATION—DATA ANALYSIS

(12)

LEVEL III

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by
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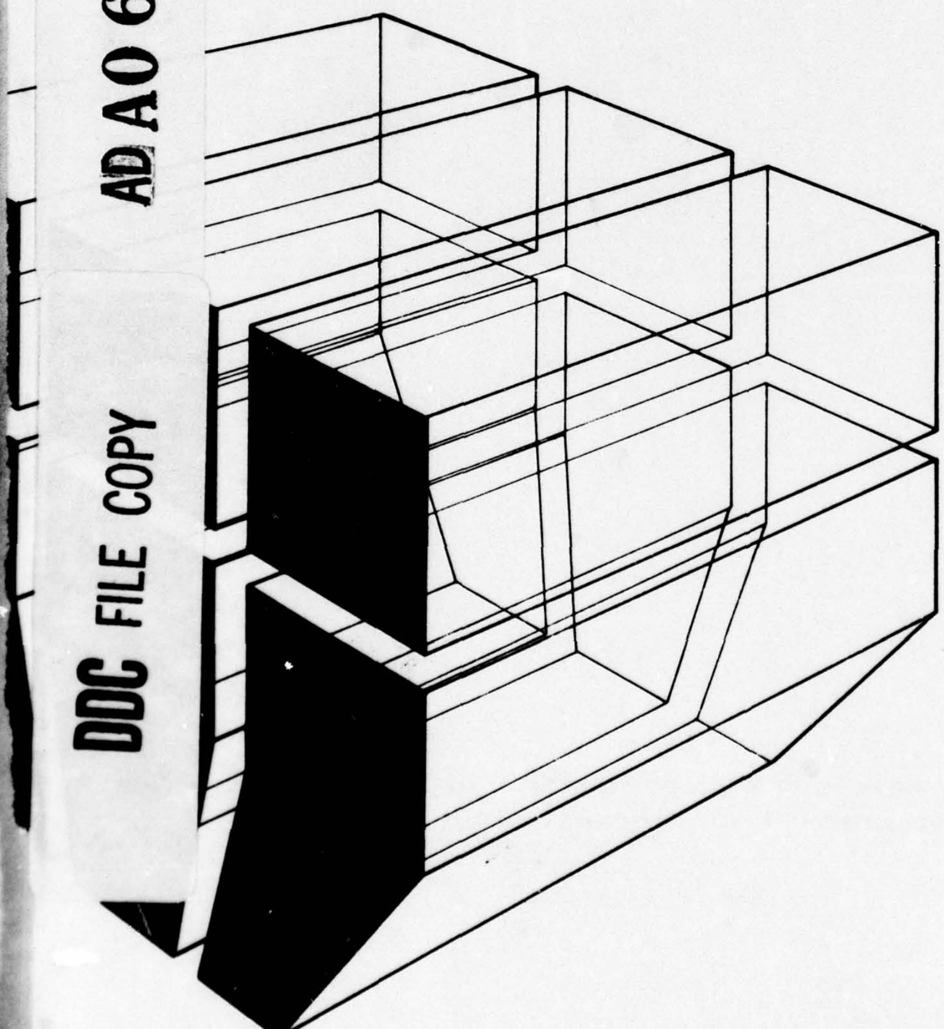

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This report describes the analysis of energy consumption data collected between September 1976 and February 1978 for selected Army buildings at Fort Belvoir, VA, Fort Carson, CO, and Fort Hood, TX. These buildings represent seven major energy consumer groups found on Army installations: family housing, troop housing, administration/training, production/maintenance, medical/dental, storage, and community support facilities. Results of analyses of building energy consumption vs. building floor area and weather parameters are presented in Btu/sq ft/heating degree days (HDD) and kWh/sq ft/cooling

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degree days (CDD) for each consumer group. Comparisons between consumer groups are shown graphically on bar charts; energy use data for each consumer group are used to develop charts showing installation energy use by consumer groups.

FOREWORD

This work was performed for the Directorate of Facilities Engineering, Office of the Chief of Engineers (OCE), under Project 4A762731AT41, "Design, Construction, and Operation and Maintenance Technology for Military Facilities"; Technical Area 06, "Energy Systems"; Work Unit 007, "Fixed Facility Energy Consumption Investigation." Mr. J. Walton served as the OCE Technical Monitor.

This work is a joint effort of the U.S. Army Facilities Engineering Support Agency (FESA) and the Energy Branch (EPE), Energy and Power Division (EP), U.S. Army Construction Engineering Research Laboratory (CERL).

Appreciation for their outstanding support during data collection is expressed to the following post facilities engineering personnel: Mr. K. Hoppe of Fort Belvoir, VA, Mr. M. Davis and Mr. S. Anderson of Fort Hood, TX, and Mr. F. Florian, Mr. J. Wiegal, and Mr. DeAngelis of Fort Carson, CO.

COL J. E. Hays is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director. Mr. R. G. Donaghy is Chief of EP. COL R. Miller is the Commander and Director of FESA and Mr. C. Smith is the Technical Director.

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FIXED FACILITIES ENERGY CONSUMPTION INVESTIGATION–DATA ANALYSIS

1 INTRODUCTION

Background

The increased cost of fuel and electricity during and following the energy crisis of 1973 and 1974 adversely affected Army installation operations and budgets and became a subject of concern to installation commanders, Major Commands, and the Office of the Chief of Engineers (OCE).

OCE therefore initiated a study of the energy problem on Army fixed facilities.[1] As various areas for investigation were identified, it became apparent that a knowledge of the energy consumption patterns of facilities on Army installations was required. This need resulted in formulation of the Fixed Facilities Energy Consumption Investigation (FFECI).

Objective

The objective of the overall FFECI is (1) to collect data relating to the flow, demand patterns, and uses of the various forms of energy consumed on Army installations, (2) to compile a data file for use in later analysis, and (3) to analyze the collected data to determine how the energy was consumed.

This report documents part of the phase of study (Step 8, below) which is intended to provide Facilities and District Engineers with (1) a summary of installation energy use data that have been collected from September 1976 to February 1978, (2) an analysis of a full year's data with respect to consumer groups and climatic conditions, and (3) a comparison of energy usage including a breakdown of installation energy consumption by consumer group.

Approach

FFECI is being conducted in the following steps:

1. Determination of potential Army users of energy usage information and their data requirements

2. Selection of specific Army posts and major consumer groups for monitoring based on size, geographical location, weather, mission, and Major Command

3. Selection of specific buildings in each major group for application of instrumentation

4. Selection and procurement of required instrumentation and monitoring systems to record energy use on an hourly basis

5. Installation of instrumentation and interfacing and recording equipment at energy sensor locations

6. Development and maintenance of a data base management system for storage, retrieval, and analysis of energy consumption data

7. Provision to potential users of energy consumption data with a report of energy data available, metering system used, and how to obtain consumption data

8. Provision of reports on analyses of collected data to indicate how major installations use energy.

Steps 1 through 7 are detailed in CERL Interim Report E-127 and the Facilities Engineering Support Agency's (FESA's) Report FESA-RT-2041.[2]

CERL Interim Report E-120 documents the first phase of Step 8;[3] the second phase is reported here.

Mode of Technology Transfer

Results of the FFECI will be published as a Department of the Army (DA) Technical Bulletin.

2 SUMMARY OF FFECI STUDY

The first step of FFECI was to define the users and uses of building energy data. Military users identified were Facilities Engineers, Major Commands, Corps District and Division Engineers, OCE, and research laboratories. The energy data needs of these users

[1] Disposition Form, Subject, Energy Consumption Investigation (Research and Development Office, Office of Chief of Engineers [OCE], 26 August 1974).

[2] L. M. Windingland, B. J. Sliwinski, *Fixed Facilities Consumption Investigation–Data Users Manual*, Interim Report E-127/ADA051678 (U.S. Army Construction Engineering Research Laboratory [CERL], February 1978); K. Dempsey, E. R. Love, G. Aveta, *Fixed Facilities Energy Consumption Investigation: Interim Report for the Period August 1974 to December 1976*, Report FESA-RT-2041 (Facilities Engineering Support Agency [FESA], May 1978).

[3] L. M. Windingland, B. J. Sliwinski, and A. R. Mech, *Fixed Facilities Energy Consumption Investigation–Initial Data Report*, Interim Report E-120 (CERL, January 1978).

ranged from yearly consumption totals for various building types to hourly energy usage patterns for detailed building energy consumption analysis. This variety of needs necessitated use of metering devices that would record building energy consumption on an hourly basis.

Since all Army buildings at all installations could not be monitored, the next step was to select a representative sample of installations and buildings. Three Army posts were selected: Fort Belvoir, VA, Fort Carson, CO, and Fort Hood, TX. These installations represented two major Army commands (TRADOC and FORSCOM) in order to provide data on facility energy use on posts with different missions. Two posts in the same command (Fort Carson and Fort Hood) were of different sizes, permitting determination of the effects of size on energy use profiles. Since they are also in different geographical areas (eastern seaboard, southwest and west), a study of the differences in energy use for various building construction types in different climates was possible.

In order to select the representative buildings to be monitored on these three installations, Army buildings were divided into consumer groups based on the Army real property indexing system, which separates facilities into more than 40 different building categories. These 40 categories were consolidated into seven major energy consumer groups representing different post functions: troop housing, family housing, administration/training, medical/dental, and community support, storage, and production/maintenance facilities. Nearly every building on the three Army posts falls into one of these consumer groups. In addition, portions of each installation's utility distribution system were monitored. The Department of Energy has established 12 building categories which may be used in future breakdowns of building energy consumption. Table 1 provides a cross reference of the consumer groups used in this report and the DOE Building Categories.

Finally, representative buildings in each consumer group were selected for energy usage monitoring. The selection was made to be representative of the construction types and eras found in the study's building inventory (e.g., World War II type, 1960s I-type, and modern Army standard design types were selected in the troop housing category). In some instances, identical buildings were chosen for comparison of operations and control system variation. Similar buildings at two different locations were also chosen to determine the effects of weather on energy consumption. Table 1 lists the number of buildings of each type monitored at each installation. A total of 114 buildings were selected for monitoring.

Once the energy parameters to be monitored in each building were determined, instrumentation systems and recording devices were procured and installed. The energy parameters selected generally included all energy being used to operate the buildings, such as total natural gas consumption and total electrical consumption. Some buildings, however, were selected for

Table 1
Summary of Buildings Being Monitored

	Fort Carson	Fort Belvoir	Fort Hood	Total	DOE Building Category(s)
Troop Housing					
Barracks	9	6	11	26	Housing (Bachelor)
Dining Facilities	2	1	3	6	
Family Housing	4	9	10	23	Housing (Family)
Administration/Training	5	3	8	16	Research and Development, Office, and School
Medical/Dental	1	1	4	6	Hospital
Storage	2	2	1	5	Storage
Production/Maintenance	5	2	5	12	Service
Community Support Facilities	4	5	11	20	Institutional, and Service
Utility Distribution	13	11	23	47	Utilities
Total	45	40	76	161	

detailed energy analysis. At these sites, in addition to monitoring total energy usage, building temperatures, and humidity, certain portions of the electrical systems (such as chiller power and lighting power) and certain operating parameters of mechanical systems were monitored. A complete weather station was installed at each post for onsite monitoring of ambient temperature, dewpoint temperature, solar radiation, windspeed, wind direction, and barometric pressure. Approximately 400 data points were chosen for monitoring in the 114 buildings.

A data storage system was developed for filing the incoming energy use data and programs were written to assist individuals who wish to access and analyze portions of FFECI data that may apply to their particular interests.

The steps discussed above are described in detail in the FFECI Data Users Manual.[4] The manual describes what data are available, and the methods for obtaining actual consumption data. The manual also gives the energy data locations and the energy parameters monitored by FFECI, and fully describes the instrumentation systems used during the study.

3 ANALYSIS AND FINDINGS

Method of Analysis

Since one of the major objectives of FFECI was to determine how energy is used on an installation, energy consumption was divided into electrical consumption (including cooling) measured in kilowatt hours (kWh), and heating energy consumption measured in British thermal units (Btu). This energy consumption was then analyzed on a monthly basis for each of the seven consumer groups. Effects of weather were studied by analyzing energy consumption as a function of Heating Degree Days (HDD) and Cooling Degree Days (CDD). This functional relationship was determined from regression analysis of the energy consumption data from each consumer group based on monthly consumption data and associated HDD and CDD. Monthly energy consumption data were analyzed, based on daily HDD and CDD and average daily energy consumption. A monthly total was divided by the number of days in the month to account for varying days in the months and monitoring periods as described in Appendix A. Because buildings within each consumer group and among consumer groups varied greatly in size, regression analyses were performed on the basis of Btu and kWh consumed per square foot of building floor area so that comparisons between buildings would be meaningful. The regression analysis method resulted in linear equations giving Btu/sq ft/day and kWh/sq ft/day as a function of HDD and CDD for each consumer group. The equations are in the form:

$$E_h = a_1 + b_1 \times HDD_d \qquad \text{[Eq 1]}$$

$$E_e = a_2 + b_2 \times CDD_d \qquad \text{[Eq 2]}$$

where E_h = daily heating energy consumption (Btu/sq ft/day)
E_e = daily electrical consumption (kWh/sq ft/day)
HDD_d = daily heating degree days
CDD_d = daily cooling degree days
a_1, a_2, b_1, b_2 = regression parameter

The details of the regression analysis leading to the regression parameters for each consumer group are given in Appendix A.

Energy Analysis by Consumer Group

Family Housing

The analysis of family housing heating energy usage data showed a good correlation* between heating energy consumption and daily heating degree days (HDD_d). Analysis done on individual buildings resulted in better correlation than analysis done among all buildings, which showed considerable scatter. This indicated that part of the scatter in the final correlation is due to building construction type and location. The equation obtained for all family housing units on all posts was:

$$E_h = 105.6 + 20.02 \times HDD_d \text{ (Btu/sq ft/day)} \qquad \text{[Eq 3]}$$

The constant 105.6 represents heating energy usage which occurs for zero HDD and loads such as hot water and cooking.

The analyses of family housing electric usage data showed a good correlation with daily cooling degree days (CDD_d) when data were taken from buildings

[4] L. M. Windingland and B. J. Sliwinski, *Fixed Facilities Energy Consumption Investigation–Data Users Manual*, Interim Report E-127/ADA051678 (CERL, February 1978).

*The term "good correlation" will be used in this report to describe certain functional relationships. The statistical meaning of this term, based on regression analysis and R^2 values, is detailed in Appendix A.

with air conditioning. Part of the scatter in this correlation is because some buildings use window units and some use central units. The equation obtained for all family housing units with air conditioning was:

$$E_e = .01447 + .001683 \times CDD_d \quad \text{(kWh/sq ft/day)} \qquad \text{[Eq 4]}$$

In this case, the constant .01447 represents the electric usage which occurs for zero CDD and loads such as lights and appliances.

Buildings without air conditioning showed no correlation with CDD; for these buildings, a value of .01659 kWh/sq ft/day was obtained from regression analysis for daily electric usage. This value was in good agreement with the value obtained for buildings with air conditioning at zero CDD.

Barracks

Analysis of heating energy usage data for barracks showed poor correlation with HDD when no groupings were made with respect to the barracks' year of construction. However, when the year of construction was taken into account, good correlations resulted. The barracks were divided into three categories with respect to age: barracks built prior to 1966, including World War II type, which are designated as "old"; barracks built after 1966 with the exception of the modern Army modular type, which are designated as "new, nonmodular"; and barracks of the modern Army modular type, which are designated as "modular." Appendix C provides examples of these types. The equation obtained for daily heating energy usage by *old* barracks built prior to 1966 was:

$$E_h = 130.5 + 15.99 \times HDD_d \text{ (Btu/sq ft/day)} \qquad \text{[Eq 5]}$$

For barracks built after 1966, excluding the modular type, the equation was:

$$E_h = 81.91 + 7.4 \times HDD_d \text{ (Btu/sq ft/day)} \qquad \text{[Eq 6]}$$

As indicated in Eqs 5 and 6, the new, nonmodular barracks use about half the energy per HDD_d as the old barracks.

When data from modular barracks were included in the regression analysis with other barracks built after 1966, poor results were obtained. When these data were grouped separately, however, the results were good. The heating energy for modular barracks is supplied by hot water from a central plant. The equation obtained for daily heating energy usage for the new modular barracks was:

$$E_h = 295.9 + 34.21 \times HDD_d \text{ (Btu/sq ft/day)} \qquad \text{[Eq 7]}$$

This indicates that the modular barracks in this sample use approximately four to five times the amount of heating energy per HDD as new, nonmodular barracks.

Analysis of electric energy usage data taken from barracks with air conditioning built after 1966 (excluding modular type) showed reasonable correlation with CDD. Some of the scatter results because some of the buildings are cooled by central chillers which use water-cooled condensors; this increases the effect of dewpoint temperature on energy consumption. The equation obtained for daily electric energy usage for barracks with air conditioning was:

$$E_e = .01516 + .001273 \times CDD_d \quad \text{(kWh/sq ft/day)} \qquad \text{[Eq 8]}$$

For barracks without air conditioning, the value obtained from the regression analysis for daily electric usage was .0152 kWh/sq ft. This does not include World War II barracks built between 1941 and 1945; for these buildings, a value of .0065 kWh/sq ft was obtained from the regression analysis.

Administration/Training Facilities

Analysis of heating energy usage data for administration/training buildings showed a good correlation with HDD. Some of the scatter results from variations in building type, site, and usage. For example, some of the buildings were administration/classroom buildings and others were administration/supply. The supply buildings in particular were likely to have large air infiltration rates at certain times. The equation obtained for daily heating energy usage for administration/training buildings was:

$$E_h = 76.71 + 18.97 \times HDD_d \text{ (Btu/sq ft/day)} \qquad \text{[Eq 9]}$$

Data for electric energy usage did not correlate well with CDD. Averages were calculated for the months of May through September and October through April. The average daily electric energy usage for May through September was:

$$E_e = .0512 \text{ (kWh/sq ft/day)} \qquad \text{[Eq 10]}$$

For October through April the average daily electric energy usage was:

$$E_e = .0215 \text{ (kWh/sq ft/day)} \qquad \text{[Eq 11]}$$

Community Facilities

Analysis of community facility heating energy usage data showed that fieldhouse and gymnasium data correlated well with HDD. However, data from commissaries and dining facilities did not correlate well. This large scatter was not unexpected for dining facilities because a large portion of heating energy goes for cooking and hot water. The scatter in the commissary data is not understood at this point.

The equation for daily heating energy usage for fieldhouses and gymnasiums was:

$$E_h = 73.69 + 32.4 \times HDD_d \text{ (Btu/sq ft/day)} \qquad \text{[Eq 12]}$$

The equation for daily heating energy usage for the dining facilities and commissaries was:

$$E_h = 231.8 + 12.42 \times HDD_d \text{ (Btu/sq ft/day)} \qquad \text{[Eq 13]}$$

The data for community facility electric usage did not correlate with CDD. The average daily electric consumption for community facilities for May through September was:

$$E_e = .0684 \text{ (kWh/sq ft/day)} \qquad \text{[Eq 14]}$$

The average daily energy consumption for community facilities for October through April was:

$$E_e = .0662 \text{ (kWh/sq ft/day)} \qquad \text{[Eq 15]}$$

Production/Maintenance Facilities

Analysis of heating energy usage data for production/maintenance facilities* showed a large degree of scatter. This was expected because these facilities have large, high bay doors and can have very large air infiltration rates during certain maintenance activities. In addition, large amounts of heat are generated by welders, torches, and other equipment. The equation for daily heating energy consumption for production/maintenance facilities was:

$$E_h = 138.4 + 35.73 \times HDD_d \text{ (Btu/sq ft/day)} \qquad \text{[Eq 16]}$$

*Production facilities did not include major process-type production buildings such as DARCOM ammunition plants, but only those with production activities such as machining, assembly, and other activities associated with installation maintenance.

The data for electric energy consumption showed no correlation with CDD days. The value obtained for daily average electric energy usage for May through September was:

$$E_e = .0235 \text{ (kWh/sq ft/day)} \qquad \text{[Eq 17]}$$

The value obtained for October through April was:

$$E_e = .0293 \text{ (kWh/sq ft/day)} \qquad \text{[Eq 18]}$$

Medical/Dental Facilities

Analysis of heating energy data for medical/dental buildings showed a fair correlation with HDD days. The sample consisted of dispensaries and dental clinics; no hospitals were included. The equation obtained for daily heating energy for medical/dental buildings was:

$$E_h = 254.4 + 24.31 \times HDD_d \text{ (Btu/sq ft/day)} \qquad \text{[Eq 19]}$$

Data for electric usage did not correlate well with CDD. This was primarily due to differences in energy usage between buildings. The daily average energy usage for May through September was:

$$E_e = .0557 \text{ (kWh/sq ft/day)} \qquad \text{[Eq 20]}$$

The value for October through April was:

$$E_e = .0353 \text{ (kWh/sq ft/day)} \qquad \text{[Eq 21]}$$

Storage Facilities

Analysis of heating energy data for storage facilities correlated well with HDD. The equation obtained for heating energy usage for storage buildings was:

$$E_h = 35.7 + 36.1 \times HDD_d \text{ (Btu/sq ft/day)} \qquad \text{[Eq 22]}$$

None of the storage facilities in this sample were air conditioned.

The value for daily average electric energy usage for May through September was:

$$E_e = .0146 \text{ (kWh/sq ft/day)} \qquad \text{[Eq 23]}$$

For October through April the value was:

$$E_e = .0133 \text{ (kWh/sq ft/day)} \qquad \text{[Eq 24]}$$

Summary by Consumer Group

Comparisons of heating and electrical energy consumption by consumer groups are shown in Figures 1, 2, 3, and 4 and in Table 2. These comparisons are

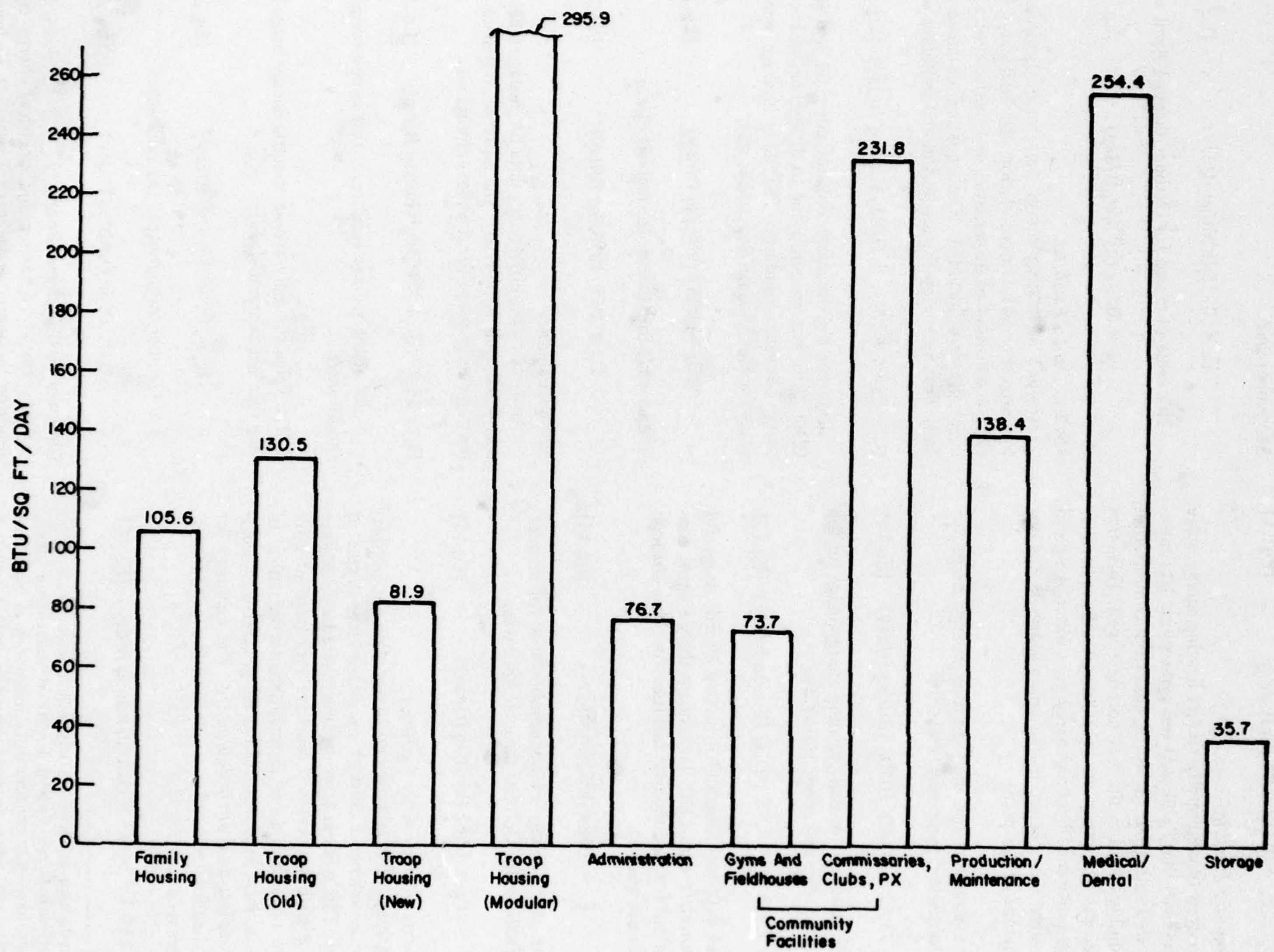


Figure 1. Zero HDD heating energy usage by consumer groups.

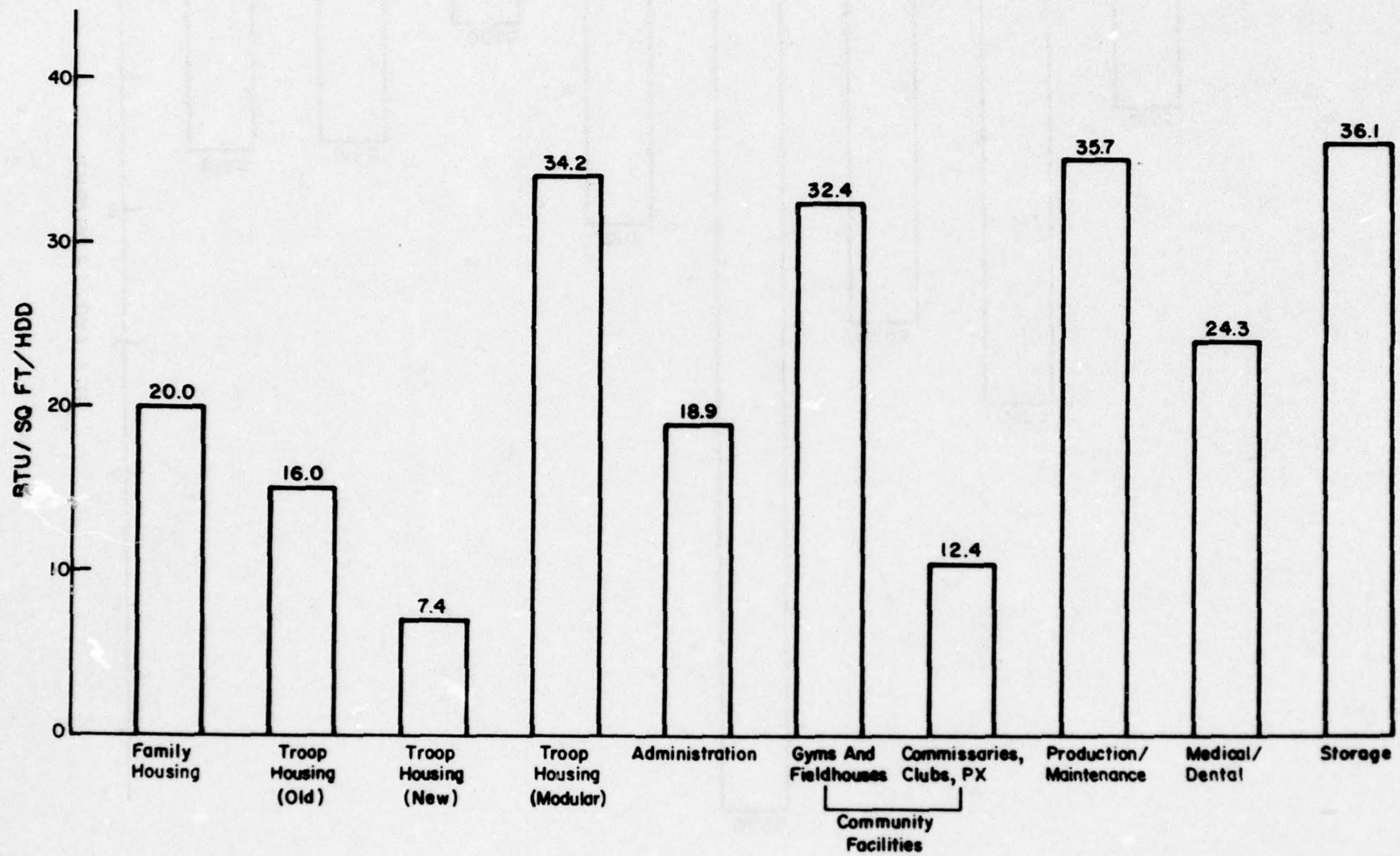


Figure 2. Comparison of heating energy usage/HDD.

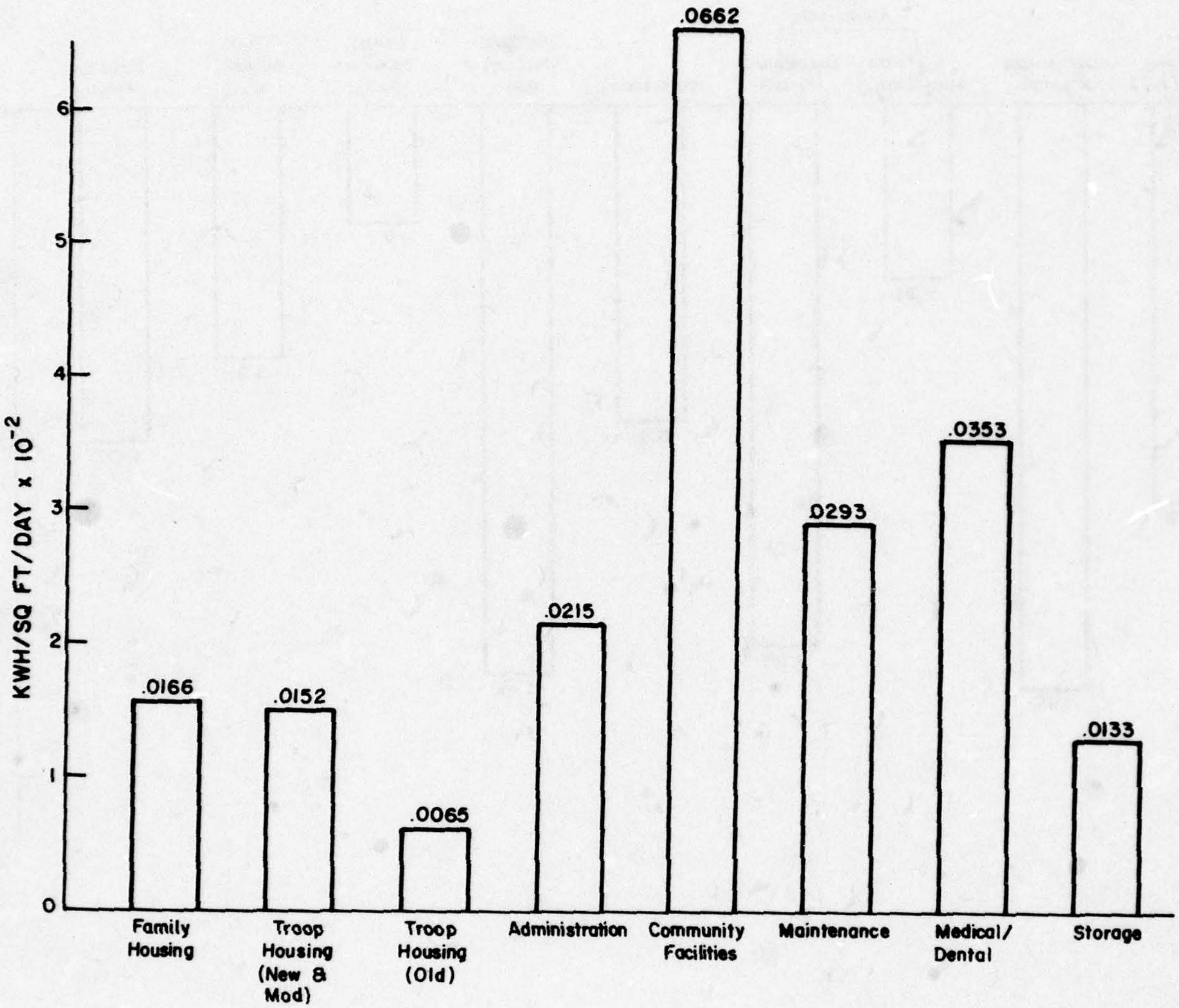


Figure 3. Daily electric energy usage for October through April.

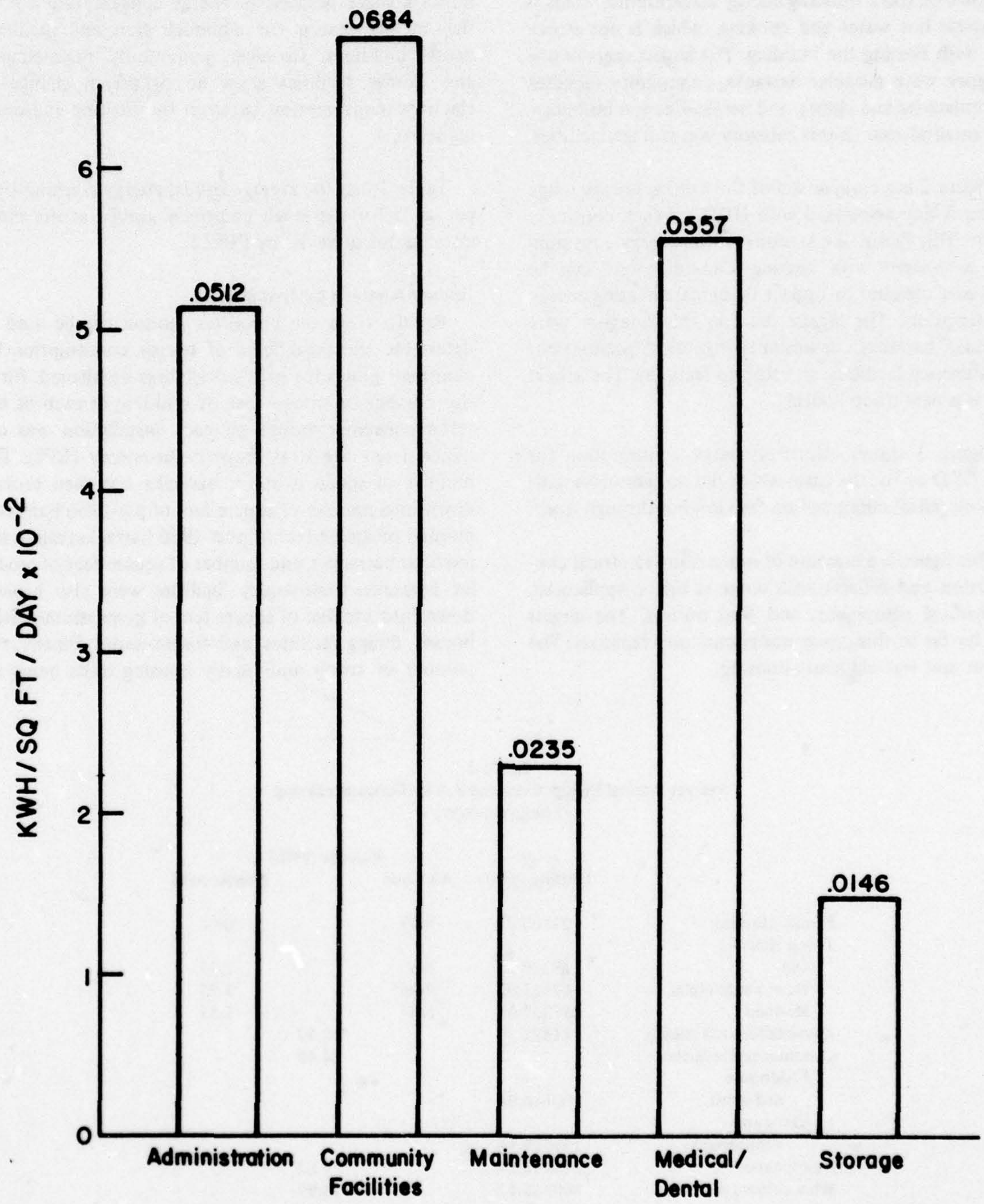


Figure 4. Daily electric energy usage for May through September.

based on the results of the analyses discussed in the preceding section.

Figure 1 shows heating consumption per sq ft/day by consumer groups for zero HDD. This value is a measure of fixed building energy consumption, such as domestic hot water and cooking, which is not associated with heating the building. The largest users in this category were modular barracks, community facilities (commissaries and clubs), and medical/dental buildings. The smallest user in this category was storage facilities.

Figure 2 is a comparison of the heating energy usage per sq ft/day associated with HDD for each consumer group. This factor is a measure of the energy consumption associated with heating a building and can be used as a measure of impact on climate heating energy consumption. The largest users in this category were modular barracks, community facilities, production/maintenance facilities, and storage facilities. The lowest user was new troop housing.

Figure 3 shows electrical energy consumption for zero CDD or for the cases which did not correlate with CDD electrical consumption for October through April.

This figure is a measure of noncooling electrical consumption and reflects such usage as lights, appliances, mechanical equipment, and wall outlets. The largest user by far in this group was community facilities. The lowest user was old troop housing.

Figure 4 shows electrical consumption per sq ft/day for May through October for those building groups whose electrical consumption did not correlate with CDD. This figure shows the impact of cooling on electrical consumption. A comparison of Figures 3 and 4 shows a sharp increase in energy consumption during the cooling season for administration and medical/dental buildings. However, community, maintenance and storage facilities show no significant change in electrical consumption between the heating and cooling seasons.

Table 2 lists the average annual energy consumption per sq ft for the seven consumer groups at the three installations surveyed by FFECI.

Energy Analysis by Installation

Results from the preceding section can be used to determine the breakdown of energy consumption by consumer group for each installation monitored. First, the number of square feet of building in each of the seven consumer groups on each installation was obtained from the Real Property Inventory (RPI). The number of square feet for barracks was then broken down into number of square feet of pre-1966 barracks, number of square feet of post-1966 barracks (minus the modular barracks), and number of square feet of modular barracks. Community facilities were also broken down into number of square feet of gymnasiums, fieldhouses, dining facilities, and commissaries. Finally, the number of troop and family housing units being air

Table 2
Average Annual Energy Consumption by Consumer Group
(Energy/sq ft/yr)

	Heating (Btu)	Electric (kWh) Air Cond		Nonair cond
Family Housing	127102.31	8.49		6.06
Troop Housing				
Old	118329.62	NA		2.37
New, nonmodular	62615.02	7.96		5.55
Modular	259257.31	NA*		5.55
Administration/Training	111871.84		12.37	
Community Facilities			24.49	
Fieldhouse and gyms	170148.05			
Clubs and commissaries	139519.96			
Maintenance	208490.24		9.82	
Medical/Dental	200338.61		15.99	
Storage	172640.63		5.04	

*Cooling supplied by central plant; individual data are not available.

Table 3
Square Footage of Consumer Groups (by Installation)

	Fort Carson	Fort Belvoir	Fort Hood
Family housing	2,912,112	2,330,092	7,244,083
Troop housing	2,666,719	1,495,754	5,932,130
*New	1,466,695	418,811	3,692,557
Modular	666,679	448,726	1,230,852
Pre-1966	553,343	628,216	1,008,720
Admin/tng & operations	949,476	1,891,199	1,427,392
Community facilities	882,605	632,409	1,762,854
*Gymnasiums	740,064	474,306	1,545,980
Commissaries	142,540	158,102	2,168,740
Production/maint	1,116,009	565,079	2,073,814
Medical/dental	711,431	332,919	401,296
Storage	652,389	510,916	863,721

*Breakdown based on Real Property Inventory, conversations with Post Facility Engineers, and visits to installations.

conditioned was determined. The results of this analysis are shown in Table 3.

The next step was to determine the number of HDD and CDD at each installation; Table 4 shows these values. Values from 1976 were used for Forts Belvoir and Carson, and values from 1977 were used for Fort Hood.

With the data available from Tables 3 and 4, the equations from the previous section were used to determine the total annual energy consumption of each consumer group at each installation. To display this energy consumption, pie charts showing percent of energy consumption (Btu and kWh) and percent of floor area were prepared to show the distribution of energy consumption at each post. These charts are shown in Figures 5, 6, and 7.

Figure 5 shows the energy and square footage distribution among consumer groups at Fort Carson. Family and troop housing accounted for the largest percentage of area and energy. The heating energy distribution for all groups closely followed the floor area distribution. The largest user of heating energy other than troop and family housing was production/maintenance; the largest user of electrical energy with the exception of troop and family housing was community facilities.

Figure 6 shows the energy and square footage distribution at Fort Hood. Again, family and troop housing accounted for the largest percentage of area and energy usage. With the exception of housing, production/maintenance and community facilities again consumed the largest portions of heating and electric energy, respectively. The distribution of heating energy paralleled the area distribution at Fort Carson.

Figure 7 illustrates the energy and square footage distribution at Fort Belvoir, where family housing and administration/training constituted the major portions of energy and area distribution. Family housing was the largest user of heating energy, while administration/training was the greatest user of electrical energy.

Validity of Analysis

In assessing the validity of the results of the analysis in the preceding section, two aspects were considered: (1) the accuracy of the collected data, and (2) how well the buildings monitored by FFECI typified their consumer groups and the installations as a whole.

The accuracy of the collected data is presented in detail in CERL Interim Report E-127.[5] As discussed

Table 4
Heating and Cooling Degree Days
(by Installation)

	HDD	CDD
Fort Belvoir	3413	1554
Fort Carson	6023	435
Fort Hood	2617	3452

[5] L. M. Windingland and B. J. Sliwinski, *Fixed Facilities Energy Consumption Investigation–Data Users Manual*, Interim Report E-127/ADA051678 (CERL, February 1978).

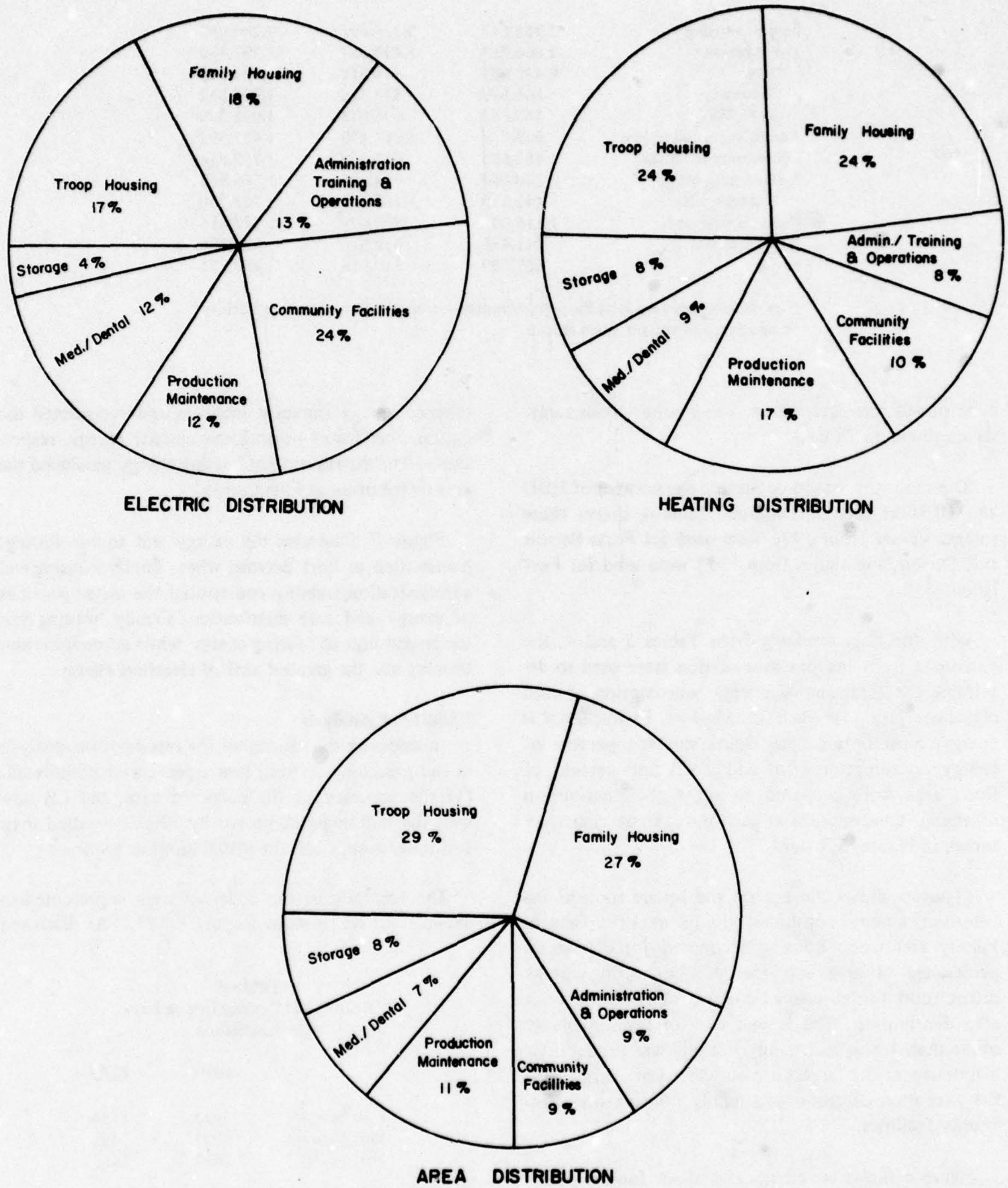


Figure 5. Energy and square footage distribution among consumer groups at Fort Carson.

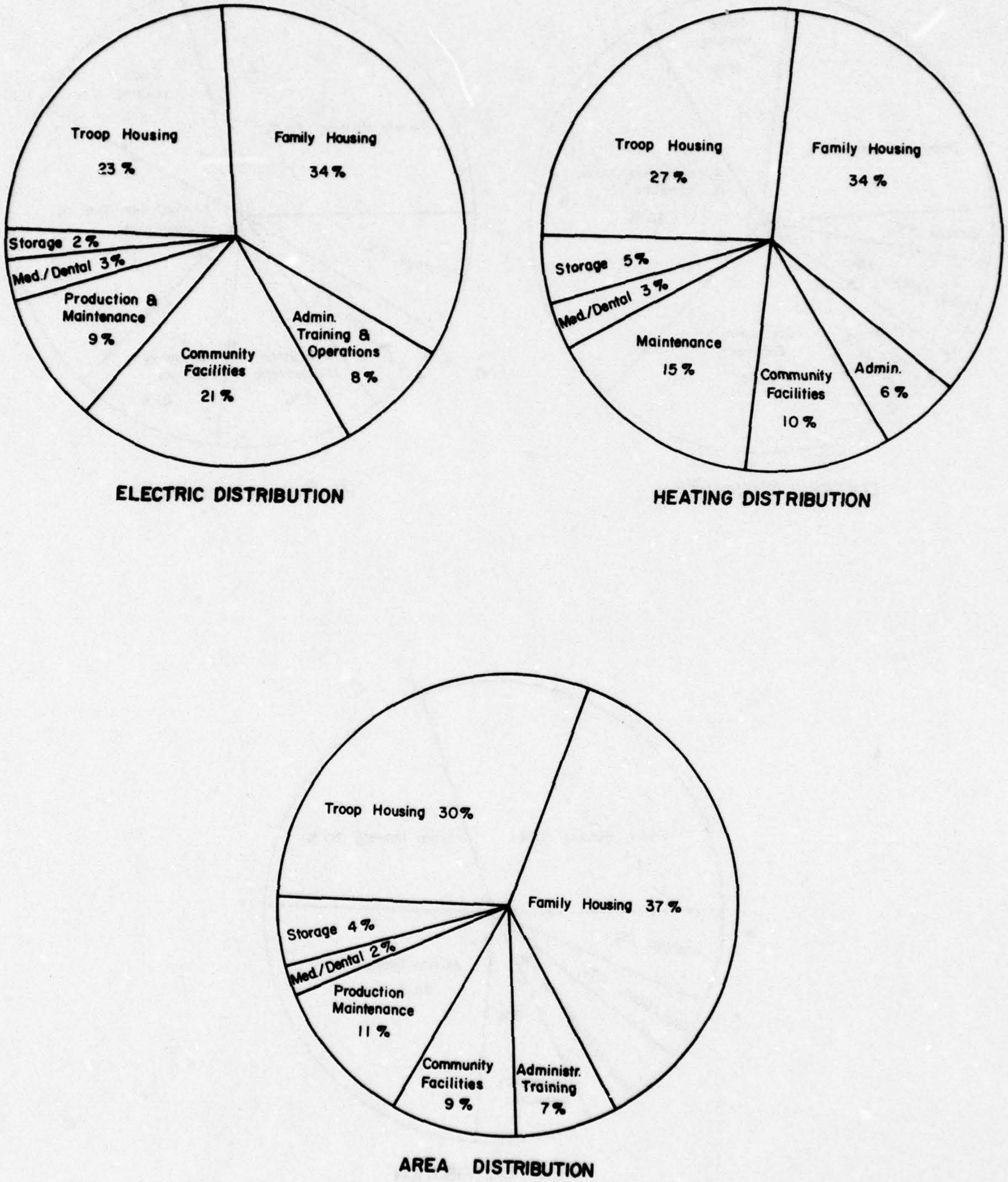


Figure 6. Energy and square footage distribution among consumer groups at Fort Hood.

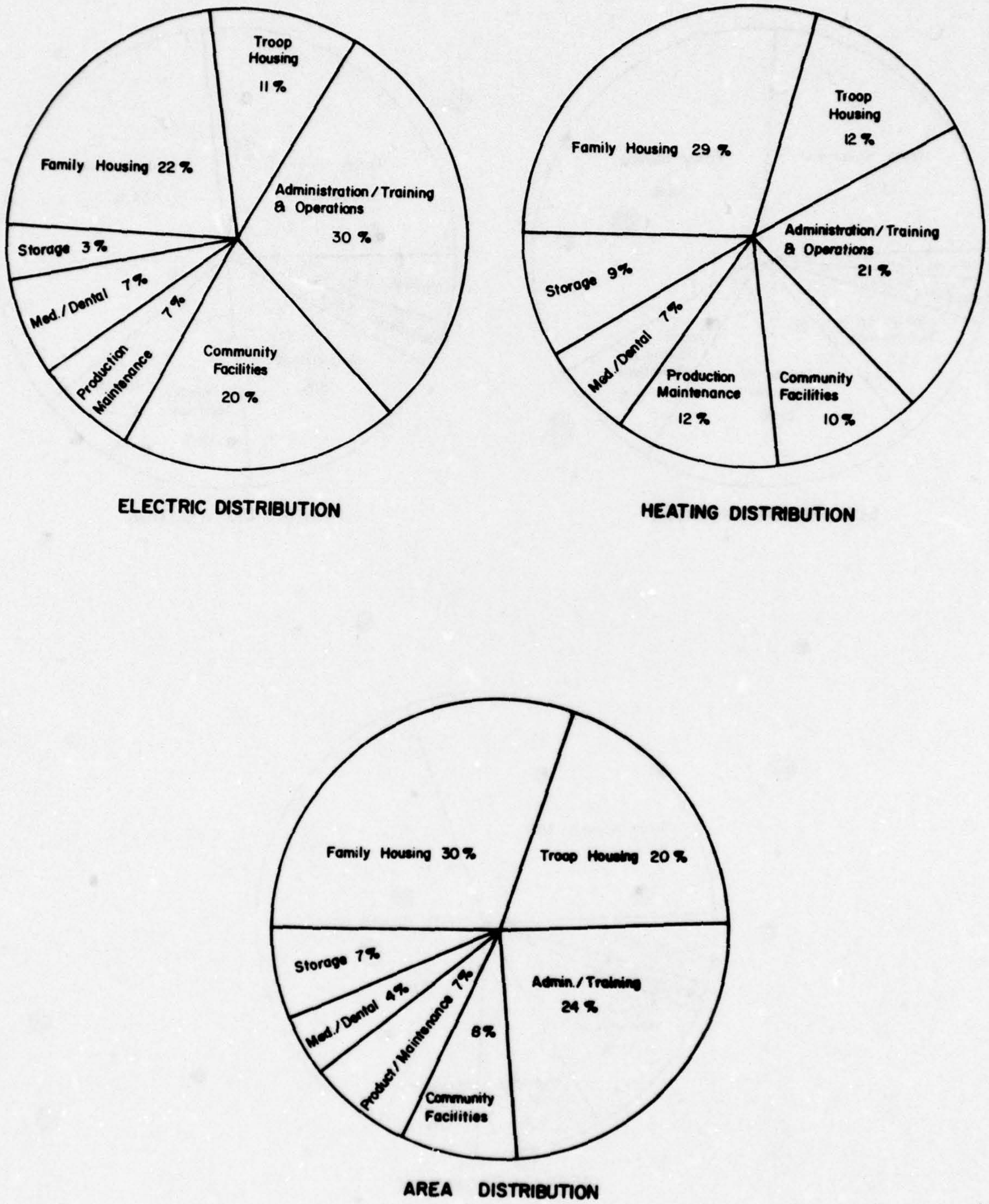


Figure 7. Energy and square footage distribution among consumer groups at Fort Belvoir.

Table 5
Comparison of Actual Vs. Predicted Energy Consumption

Fort Carson (FY76)

Heating (Btu)	Electric (kWh)	
1.67×10^{12}	7.59×10^{7}	Actual
1.80×10^{12}	9.06×10^{7}	Calculated
+7.1%	+19.4	% error

Fort Hood (FY77)

Heating	Electric	
1.70×10^{12}	2.30×10^{8}	Actual
1.94×10^{12}	2.18×10^{8}	Calculated
+14.1	−6.95	% error

Fort Belvoir (FY76)

Heating	Electric	
$.88 \times 10^{12}$	8.99×10^{7}	Actual
$.92 \times 10^{12}$	7.70×10^{7}	Calculated
+4.5	−14.1	% error

in E-127, meters used to monitor buildings in the samples were usually utility-grade meters used by utility companies for billing purposes. Meters were calibrated on a regular basis, and data were reviewed monthly to insure meter consistency and program operation. Thus it was concluded that the actual data being collected were accurate to 1 percent. To determine the validity of the building sample for which data were collected, the calculated values of energy consumption by consumer groups used to develop the pie charts in Figures 5, 6, and 7 were summed to determine total installation energy consumption. Thus, values were compared to energy consumption. Actual energy usage was obtained from the Facilities Engineers and the 1976 *Facilities Engineers Annual Summary of Operations* (OCE, 1976). (See Table 5.) The difference between actual and calculated energy consumption was less than 20 percent in all cases, indicating data used in the FFECI study was representative of the consumer groups and installation buildings.

Extension of Results to Other Installations

The application of FFECI results to other installations is primarily a problem of correcting for weather conditions and variation in installation size and function. It was for this reason that the analyses described in this report were performed. Energy consumption as a function of HDD and CDD was determined and the results were presented as energy consumptions per sq ft/consumer group. These conditions should provide good results for other installations. It should be noted that this method will not account for energy loads such as street lights, large water pumps, or other large energy users not directly connected with a building's operation. How well the data represent other installations is a question of how well the consumer groupings and the buildings selected in each consumer group typify the installation being evaluated. This question can only be answered based on an installation-by-installation analysis. Such analyses would include the development of pie charts like the ones in Figures 5, 6, and 7, and the summing of the energy consumption of each consumer group used in obtaining the pie charts to determine a total installation annual energy consumption. A comparison of this value to the actual annual energy consumption found in the *Facilities Engineers Annual Summary of Operations* would also be required. If the comparison is within 20 to 30 percent (the actual value is somewhat subjective), the results could be considered representative of the installation in question. The step-by-step procedure for conducting such analyses is described in Appendix B.

4 CONCLUSIONS

The results of data analyses to determine the functional relationships between energy consumption and heating and cooling degree days by consumer group are valid for the three installations monitored in the FFECI study. This analysis technique can be extended to other installations using the procedure in Appendix B provided the criteria described in Chapter 3 are met.

The functional relationships giving energy consumption by consumer group as a function of HDD and CDD can be used to disassociate installation energy consumption into consumption by consumer groups and to separate the heating and cooling portions of energy consumption.

The functional relationship between energy consumption and HDD and CDD provides a means of assessing the impact on energy consumption of changes in climatic conditions.

From an analysis of the pie charts and bar graphs of Chapter 3, it is concluded that the major use of energy on an installation is based on total energy consumption in family and troop housing. Thus, these two groups will have to be addressed if large-scale reductions in installation energy consumption are to be achieved. On the other hand, community facilities and maintenance facilities use the greatest amount of energy on a square foot basis. Thus, investments to encourage energy conservation in these types of facilities may prove to have the greatest payback potential.

APPENDIX A: REGRESSION ANALYSIS OF CONSUMPTION DATA

As described in Chapter 3, FFECI data analysis centered on finding equations or models of the form:

$$E_h = a_1 + b_1 \times (HDD_d)$$

$$E_e = a_2 + b_2 \times (CDD_d)$$

where E_h = daily heating energy consumption (Btu/sq ft/day)
E_e = daily electrical consumption (kWh/sq ft/day)
HDD_d = daily heating degree days
CDD_d = daily cooling degree days
a_1, a_2, b_1, b_2 = model parameter

The method of least squares fit was used to determine values for the model parameters. The usefulness of the equations was determined by using the square of the correlation coefficient, R^2. R^2 is defined as the fraction of the dependent variable variance which is accounted for by the equation. That is, it is the percentage of the variation in the data which is accounted for by the equation.

Since only one weather parameter was used, R^2 values were not expected to exceed .9. For this reason, the term "good fit" was used to describe all R^2 values between .7 and 1.0, i.e., 70 to 100 percent of the variation being represented by the regression line. The term "fair" or "reasonable" was used to describe R^2 values between .5 and .7. With the exception of some community facilities, all regressions with R^2 values of less than .5 were considered poor and discarded.

Data

Data for this report were collected from September 1976 through January 1978. Correlations were made on daily energy consumption and daily degree days. Daily data was obtained in two ways:

1. When energy use data were complete, total monthly consumption was divided by the number of days in the month to obtain a daily average. This was then correlated with the average daily degree days for the month.

2. When less than 6 months of data were available, daily energy consumption was correlated with actual daily degree days.

Degree day data used in these analyses were from National Oceanic and Atmospheric Administration (NOAA) observation stations located near each installation. The deviation between NOAA data and observations onsite was generally less than 5 percent. The installations and their respective NOAA stations were: Fort Hood--Madison Cooper Airport, Waco, TX; Fort Carson–Colorado Springs Municipal Airport, Colorado Springs, CO; Fort Belvoir–Washington National Airport, Washington, DC. The data point numbers of the buildings used in this analysis are listed in Table A1 by consumer group.

The data points listed in Table A1 are described in CERL Interim Report E-127.[6]

Use of Regression Equations

Tables A2 and A3 present a summary of the results discussed in Chapter 3. Figures A1 through A12 plot the actual data points along with the regression line and 95 percent confidence and prediction limits. Also shown in Figures A1 through A12 are the centroid of the data, Δ, R^2, Means, and Standard Deviation (Sv).

The confidence and prediction limits indicated in the figures are particularly useful, since they allow an estimation of variance likely to be encountered in predicting energy usage. The confidence limits are the *inner* lines on either side of the regression line. The distance of these lines from the regression lines provides an estimate of the deviation expected in predicting the energy usage of a group of buildings. Deviation is at a minimum at the centroid of the data.

The prediction limits are the *outer* lines on either side of the regression line. The distance of these lines from the regression provides an estimate of the deviation expected in predicting the energy usage of an individual building. As expected, this deviation is larger than the deviation for a group of buildings.

[6] L. M. Windingland and B. J. Sliwinski, *Fixed Facilities Energy Consumption Investigation–Data Users Manual,* Interim Report E-127ADA051678 (CERL, February 1978).

Table A1
FFECI Data Points

Family Housing Heat	Family Housing Elec	Troop Housing Heat	Troop Housing Elec	Administration Heat	Administration Elec	Community Facilities Heat	Community Facilities Elec
110	110	119	119	374	153	364	118
122	115	129	126	370	154	363	143
204	122	136	127	368	135	375	145
210	204	133	128	361	230	375	149
211	210	335	129	153	231	118	219
213	211	339	133	5 (total)	344	143	220
319	213	6 (total)	136		348	145	227
320	214		137		361	149	239
324	218		331		365	8 (total)	241
327	319		339		368		336
371	320		341		370		353
11 (total)	322		345		374		354
	324		221		12 (total)		362
	327		222				364
	14 (total)		226				375
			238				376
			16 (total)				16 (total)

Medical Dental Heat	Medical Dental Elec	Production Maintenance Heat	Production Maintenance Elec	Storage Heat	Storage Elec
357	147	138	138	151	366
360	233	139	139	366	152
147	359	140	140	152	236
3 (total)	360	350	234	3 (total)	3 (total)
	4 (total)	353	340		
		5 (total)	349		
			350		
			351		
			352		
			9 (total)		

Table A2
Summary of Regression Analyses (Heating)

$$E_h = a_1 + b_1\ (HDD_d)$$

	a_1	b_1
Family housing	105.6	20.03
Troop housing (old)	130.5	15.99
New nonmodular	81.91	7.40
Modular	295.9	34.21
Admin/training	76.71	18.97
Com fac/gyms	73.69	32.4
Other	231.8	12.42
Prod/maint	138.4	35.73
Med/dental	254.4	24.31
Storage	35.7	36.1

Table A3
Summary of Regression Analyses (Electric)

$$E_c = a_2 + b_2\ (CDD_d)$$

	a_2	b_2
Family housing (air cond)	.01447	.001683
(Nonair cond)	.01659	0
Troop housing (air cond)	.01516	.001275
(Nonair cond) (new–nonmodular and modular)	.0152	0
(Nonair cond) (old)	.0065	0
Admin/training (May-Sep)	.0512	0
(Oct-Apr)	.0215	0
Com fac (May-Sep)	.0684	0
(Oct-Apr)	.0662	0
Prod/maint (May-Sep)	.0235	0
(Oct-Apr)	.0293	0
Med/dental (May-Sep)	.0557	0
(Oct-Apr)	.0353	0
Storage (May-Sep)	.0146	0
(Oct-Apr)	.0133	0

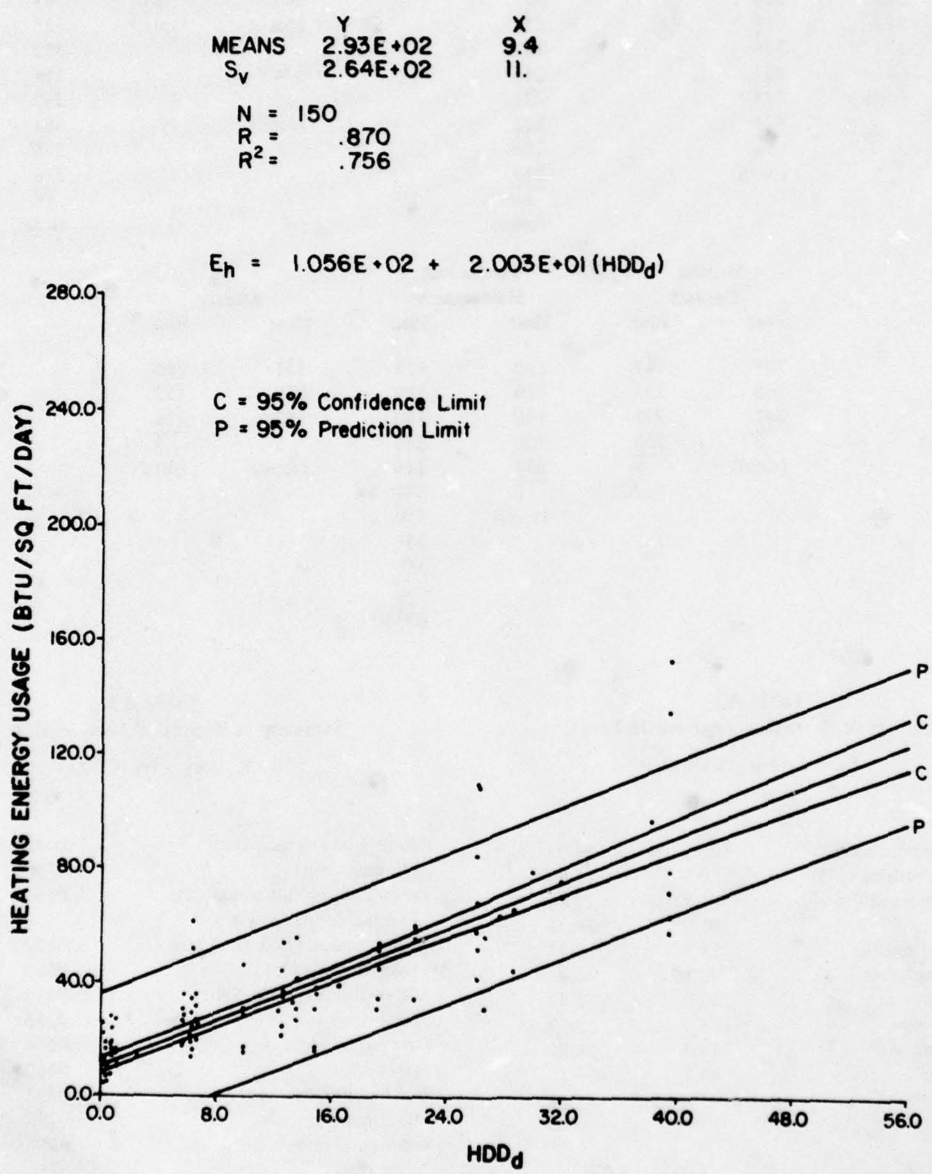


Figure A1. Family housing heating energy usage.

	Y	X
MEANS	2.70E-02	7.4
S_v	1.71E-02	8.6

N = 133
R = .846
R^2 = .715

$$E_e = 1.447E-02 + 1.683E-03\,(CDD_d)$$

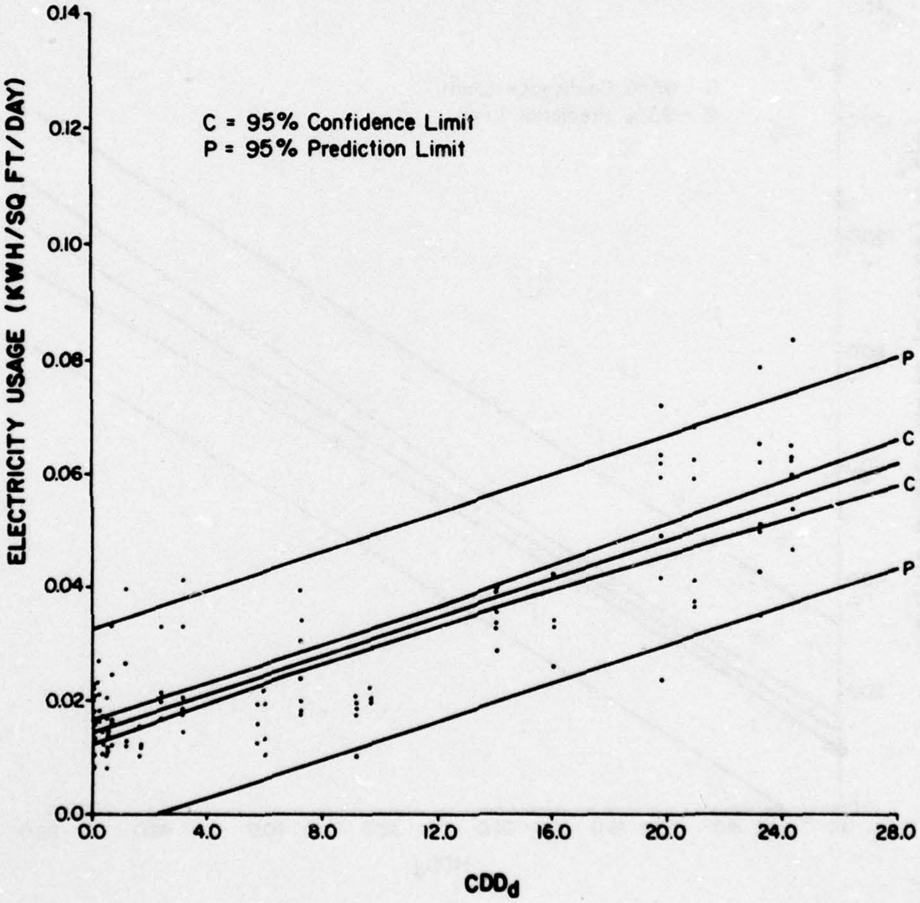


Figure A2. Family housing electric energy usage.

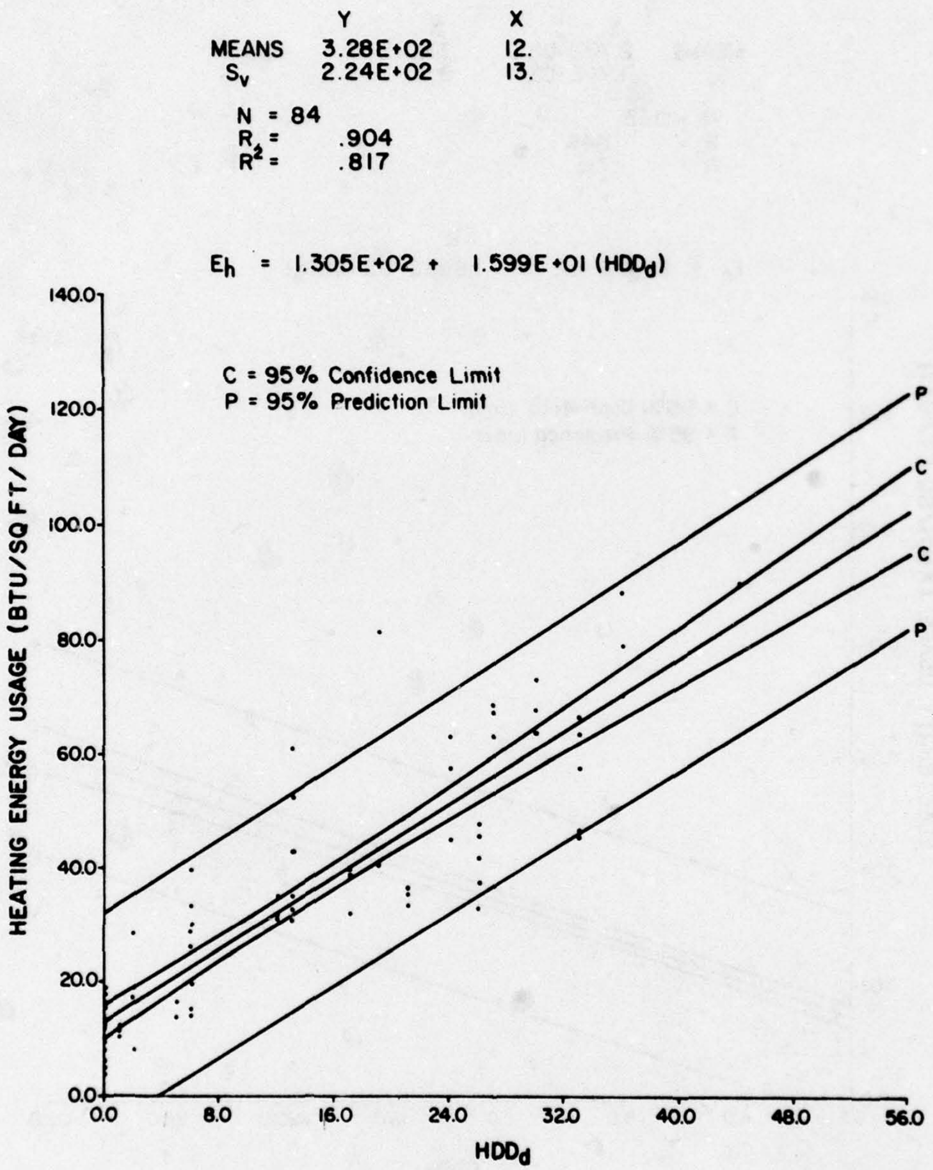


Figure A3. Old barracks heating energy usage.

	Y	X
MEANS	2.94E+02	29.
S_v	1.17 E+02	13.

N = 49
R = .851
R^2 = .725

$$E_h = 8.191E+01 + 7.400E+00 (HDD_d)$$

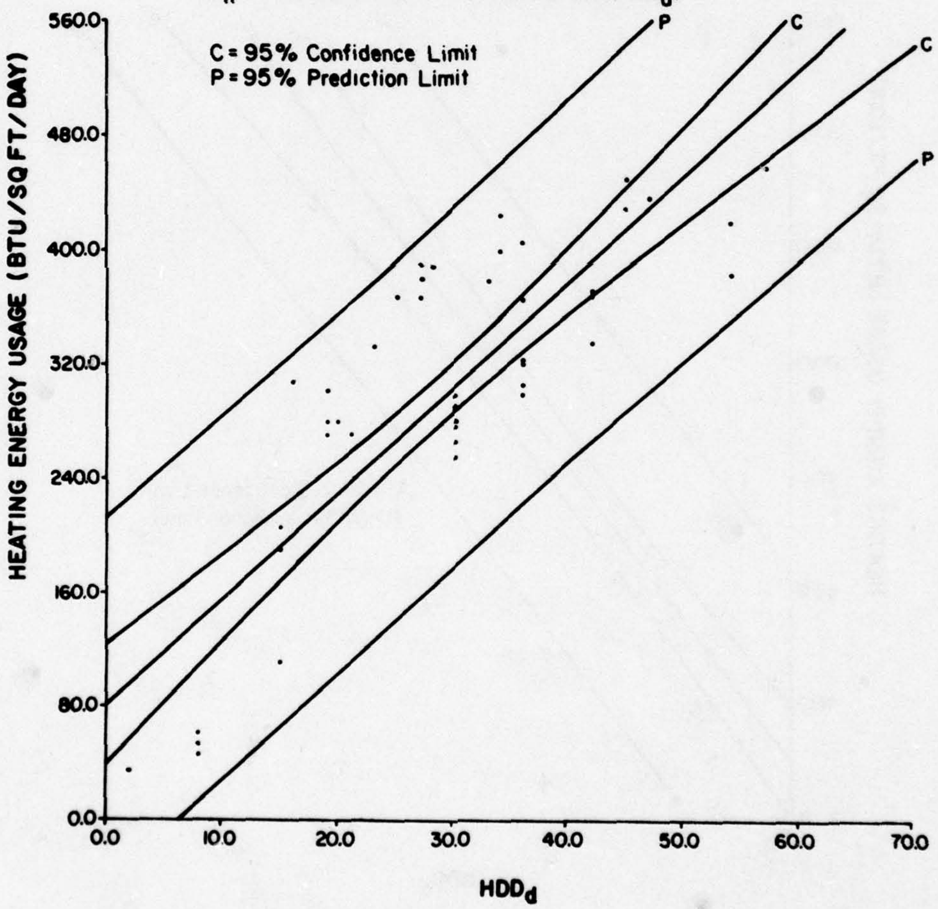


Figure A4. New, nonmodular barracks heating energy usage.

	Y	X
MEANS	7.47E+02	13.
S_v	4.34E+02	12.

N = 25
R = .931
R^2 = .867

$$E_h = 2.959E+02 + 3.421E+01 (HDD_d)$$

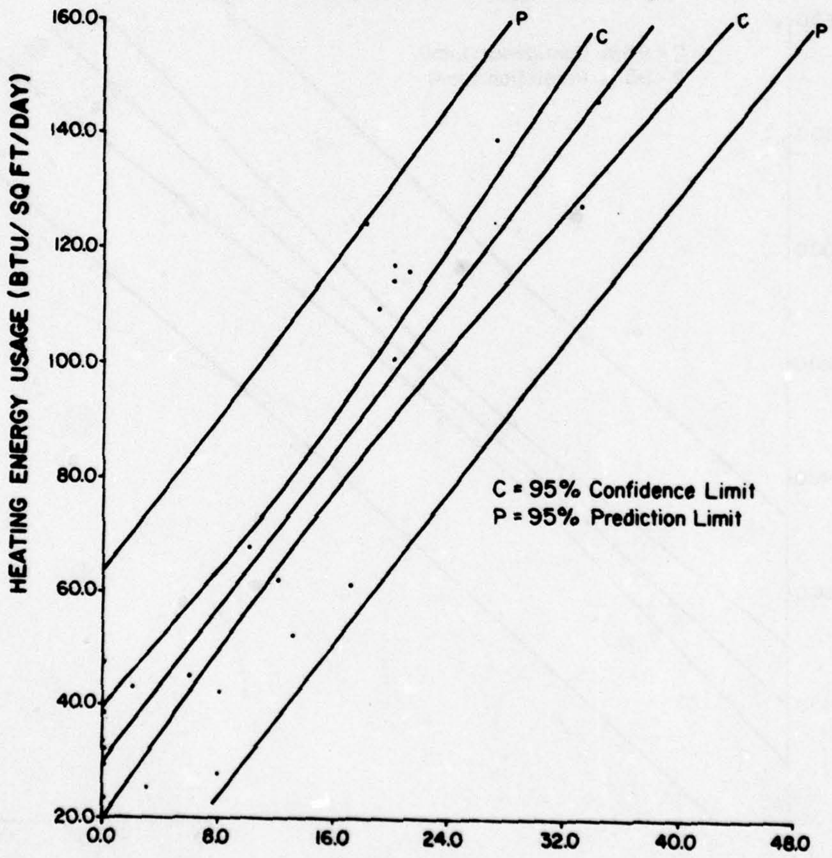


Figure A5. Modular barracks heating energy usage.

	Y	X
MEANS	2.45E-02	7.3
S_v	1.40E-02	9.0

N = 63
R = .821
R^2 = .674

$$E_e = 1.516E\text{-}02 + 1.275E\text{-}03\,(CDD_d)$$

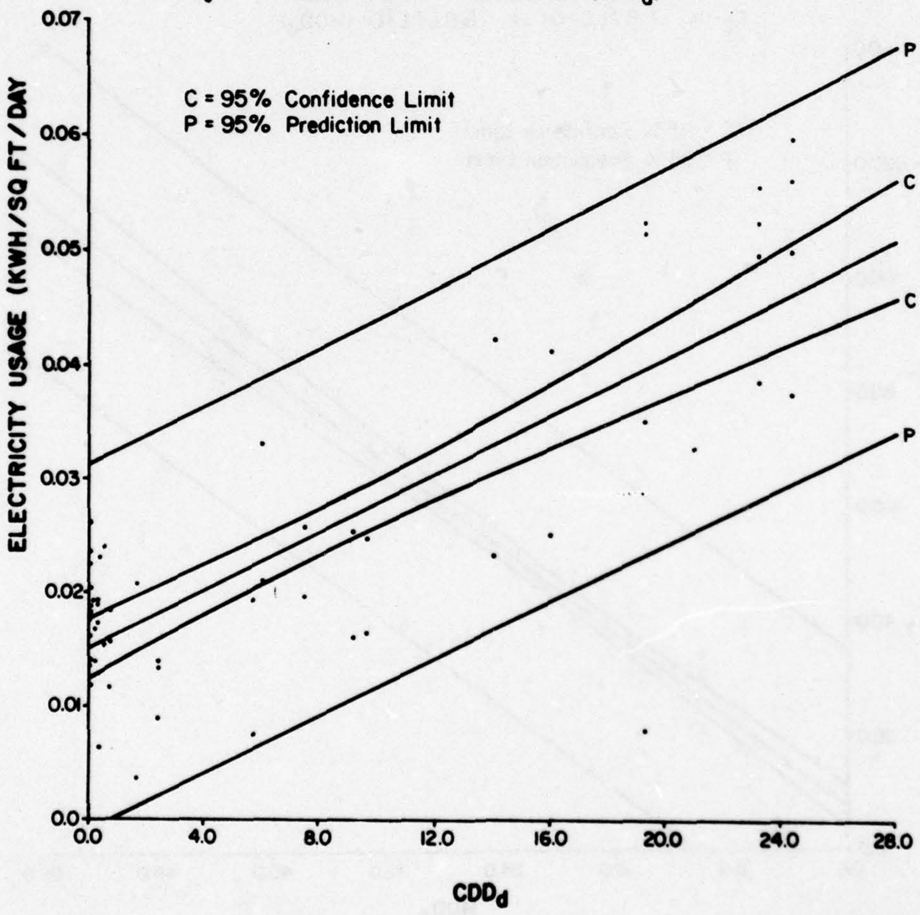


Figure A6. Air-conditioned barracks electric energy usage.

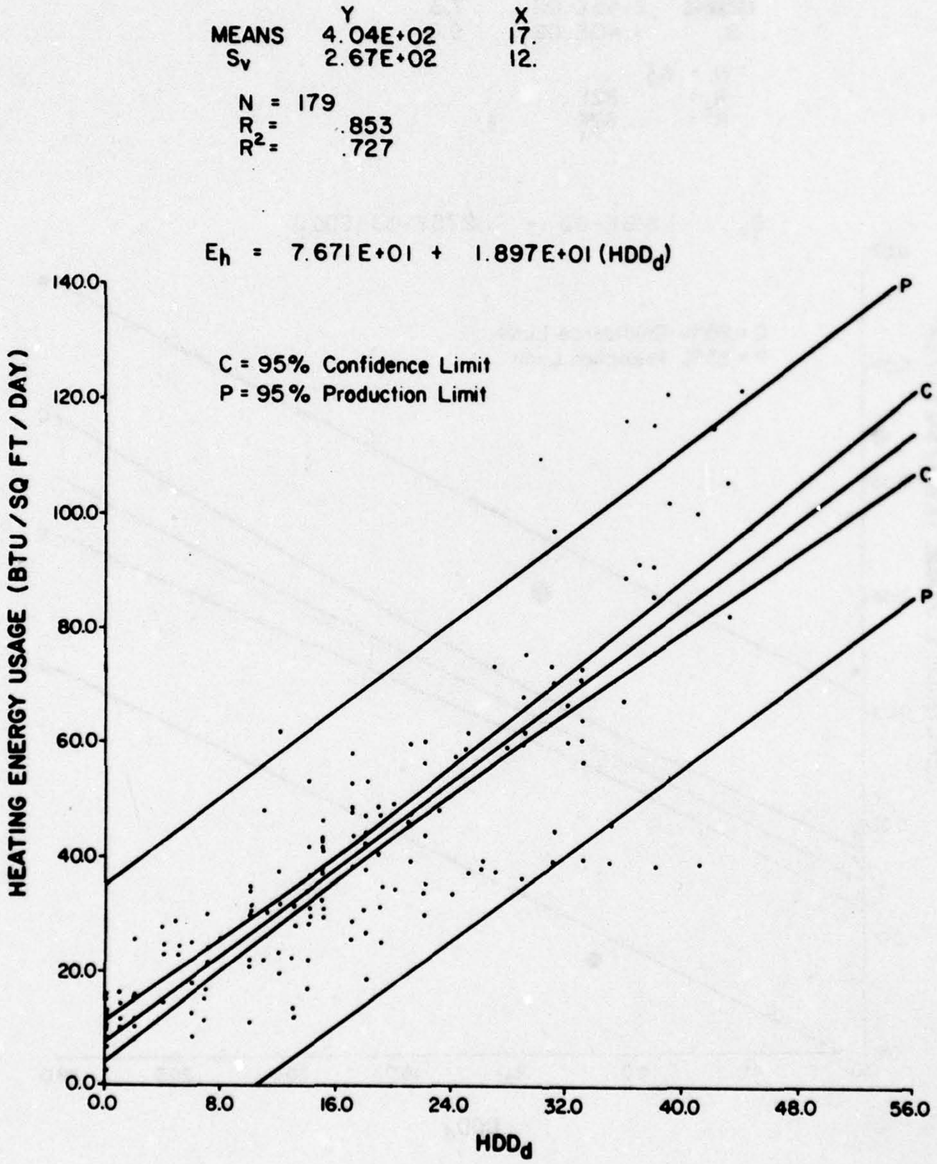


Figure A7. Administration/training facilities heating energy usage.

	Y	X
MEANS	5.50E+02	15.
S_v	4.39E+02	12.

N = 112
R = .866
R^2 = .750

$$E_h = 7.369E{+}01 + 3.240E{+}01\,(HDD_d)$$

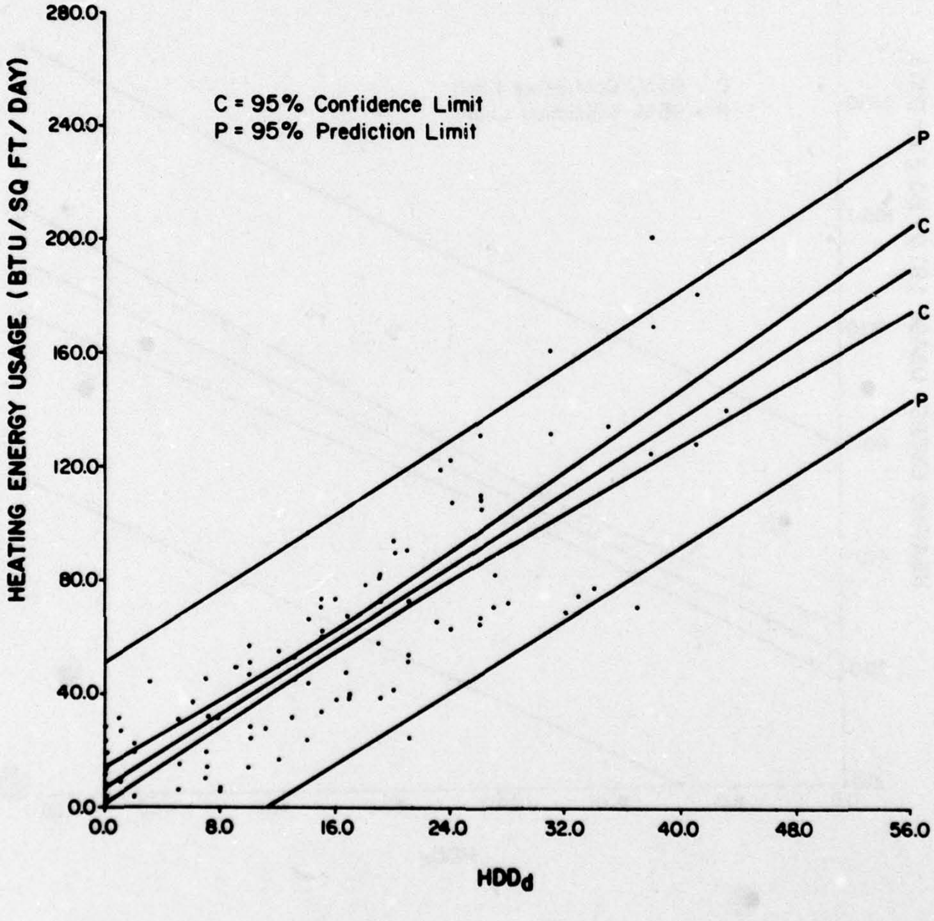


Figure A8. Community facilities (gymnasiums and fieldhouses) heating energy usage.

	Y	X
MEANS	4.49E+02	18.
S_v	2.50E+02	14.

N = 142
R = .672
R^2 = .451

$$E_h = 2.318E{+}02 + 1.242E{+}01\,(HDD_d)$$

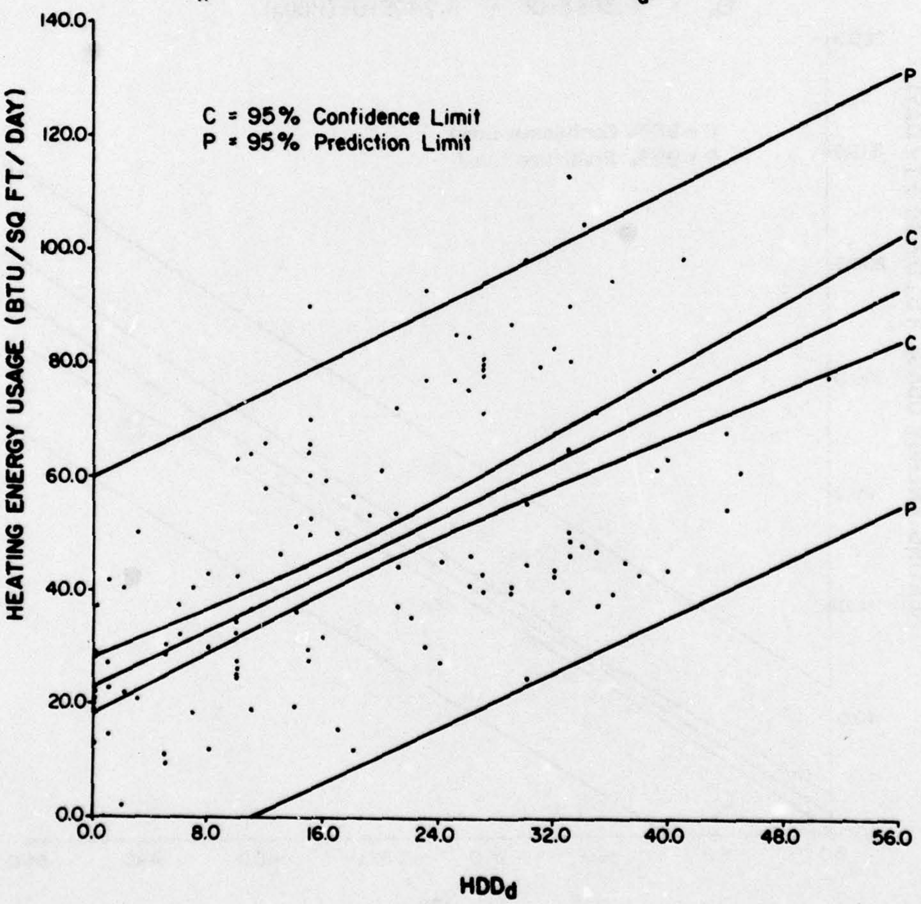


Figure A9. Community facilities (commissaries, clubs, and dining facilities) heating energy usage.

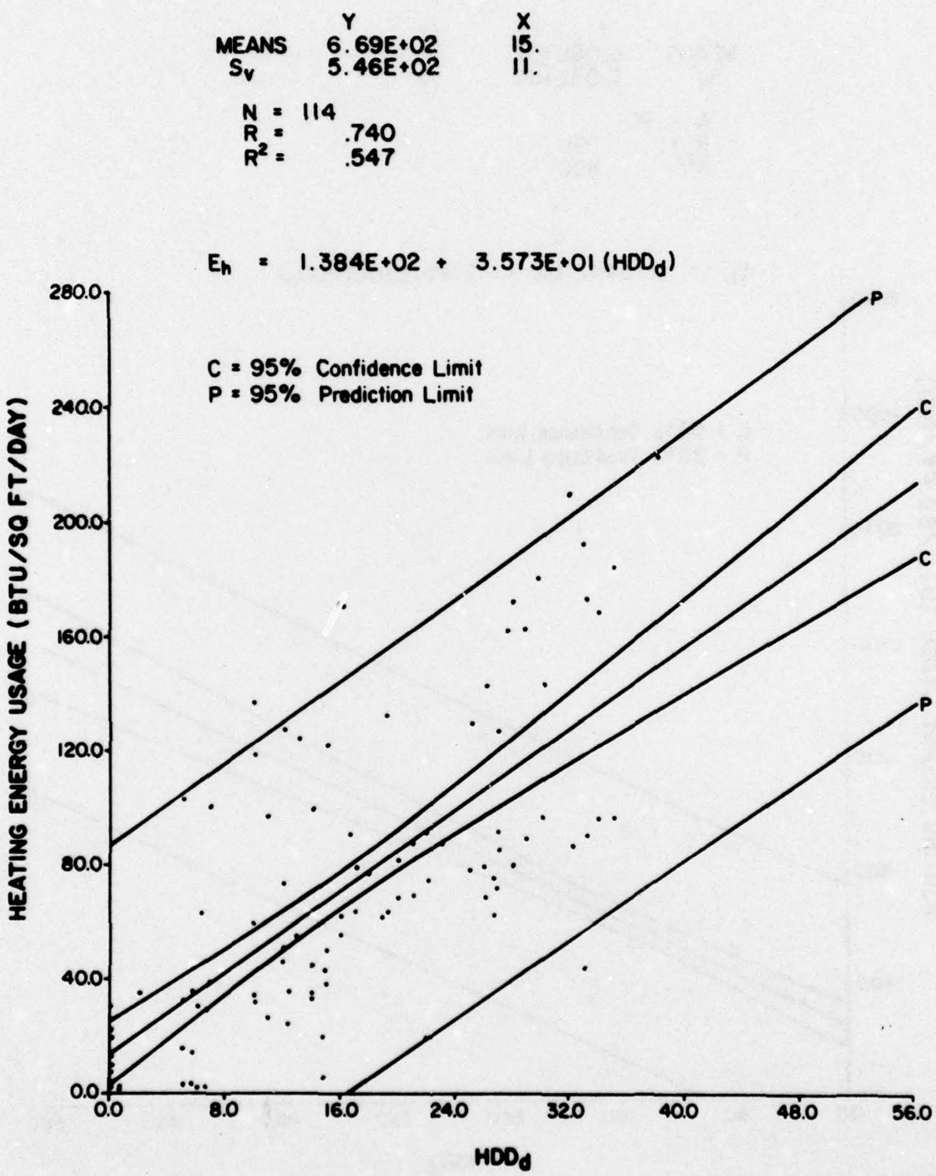


Figure A10. Production/maintenance facilities heating energy usage.

	Y	X
MEANS	6.06E+02	14.
S_v	4.03E+02	13.

N = 90
R = .791
R^2 = .626

$$E_h = 2.544E{+}02 + 2.431E{+}01\,(HDD_d)$$

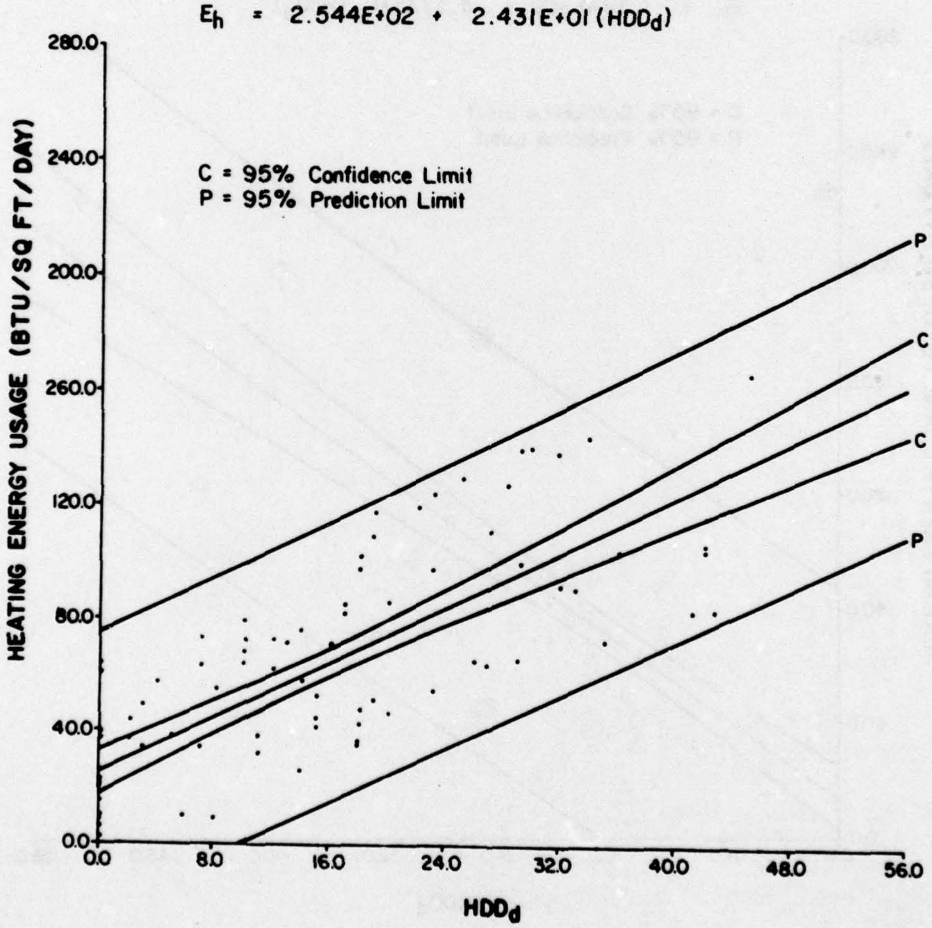


Figure A11. Medical/dental facilities heating energy usage.

Y X
MEANS 6.87E+02 18.
S_y 5.94E+02 15.

N = 33
R = .914
R^2 = .836

$$E_h = 3.573E+01 + 3.612E+01\,(HDD_d)$$

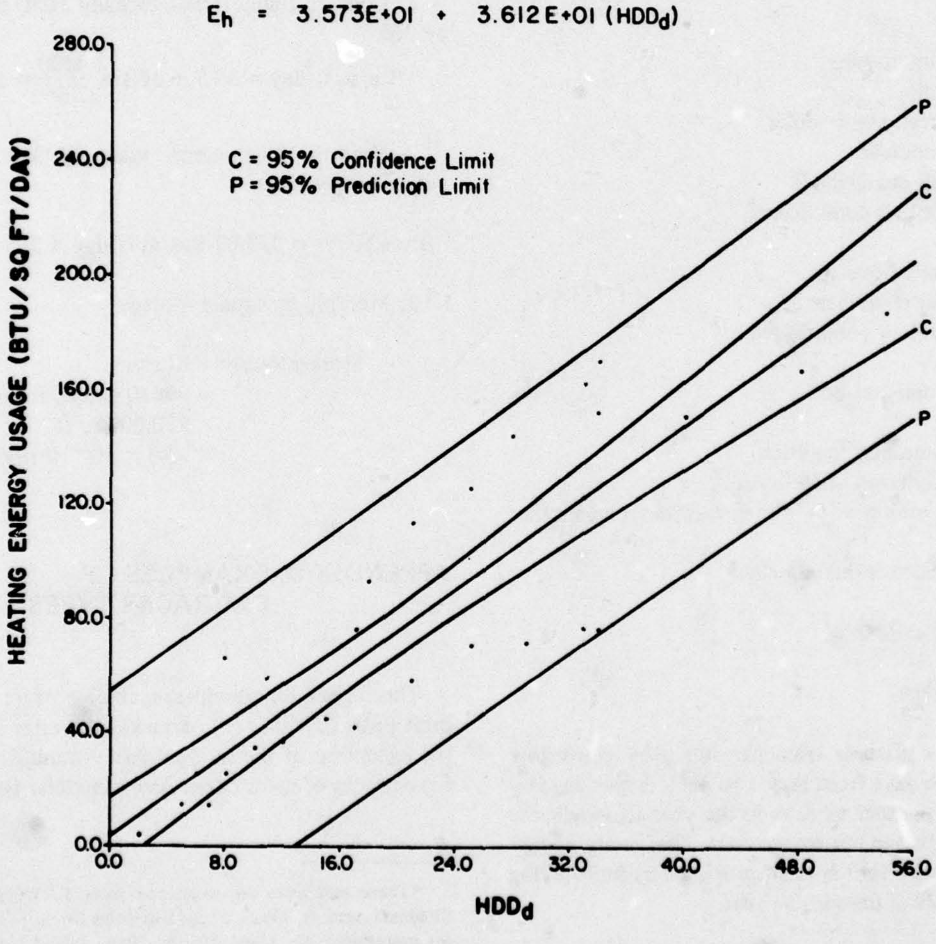


Figure A12. Storage facilities heating energy usage.

APPENDIX B: STEP-BY-STEP PROCEDURES FOR EXTENDING RESULTS TO OTHER INSTALLATIONS

The pie charts shown in Figures 5, 6, and 7 were constructed by applying the equations from Chapter 3, and obtaining square footage and heating and cooling degree data for each installation. This appendix describes a step-by-step procedure for calculating a pie chart for installations other than those surveyed by FFECI.

1. Obtain annual heating and cooling degree days from weather station near post.

2. Obtain square footage distribution of post from the post RPI for the following consumer groups and subgroups:

   a. Troop housing
      1. old
      2. new, nonmodular
      3. modular
      4. air conditioned
      5. not air conditioned

   b. Family housing
      1. air conditioned
      2. not air conditioned

   c. Administration

   d. Community facilities
      1. Gyms and fieldhouses
      2. Commissaries, dining facilities, clubs, other

   e. Production/maintenance

   f. Medical/dental

   g. Storage

3. Apply equations from Chapter 3 by converting annual degree days from Step 1 to daily degree days by dividing the number of days in the year to obtain the daily energy usage per square foot. The yearly energy usage per square foot is then calculated by multiplying by the number of days in the year.

4. Multiply values obtained in Step 3 with square footage values from Step 2 to obtain yearly usage for consumer groups.

5. Apply Steps 3 and 4 for each consumer group, sum these values and then calculate percentage of total usage accounted for by each group.

An example of Steps 3 and 4, calculation for storage facilities, energy usage, and yearly heating is shown below:

Storage square footage = 350,000

Annual HDD = 2400

Equation for daily energy usage per square foot = $35.7 + 36.1 \times HDD_d$

1. Convert annual HDD to daily HDD by dividing by 365

$$\text{Btu/sq ft/day} = 35.7 + 36.1 \times \frac{2400}{365} = 273.07$$

2. Multiply daily energy usage by 365 to obtain yearly energy usage

$$\text{Btu/sq ft/yr} = 273.07 \text{ Btu/sq ft/day} \times 365 = 99670$$

3. Multiply by square footage

$$\begin{aligned}\text{Storage yearly} &= \text{Btu/yr} \\ &= 99670 \text{ Btu/sq ft/year} \\ &\quad \times 350{,}000 \text{ sq ft} \\ &= 3.48 \times 10^{10} \text{ Btu/yr}\end{aligned}$$

APPENDIX C: EXAMPLES OF BARRACKS TYPES*

This appendix provides examples of (1) barracks built prior to 1966, (2) barracks built after 1966, with the exception of the modern Army modular type, and (3) barracks of the modern Army modular type.

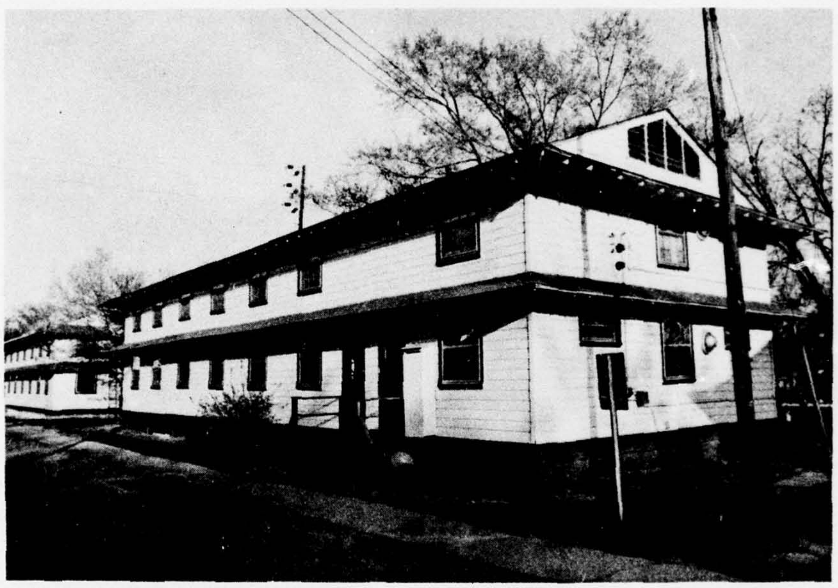
*These examples are extracted from L. Windingland, B. Sliwinski, and A. Mech, *Fixed Facilities Energy Consumption Investigation Data Users Manual*, Report E-127/ADA052708 (CERL, 1977).

Example 1 of "Old Barracks"

Fort Belvoir, VA
Building 2203
Data Point 223
Bachelor Enlisted Quarters (Barracks)

Built in 1941, this 26-person enlisted barracks without dining facilities has a total floor area of 4270 sq ft (438 m^2). The wooden structure employs a wood-rafter-supported roof with composition shingles. The building is heated with fuel oil. Listed hot water capacity is 500 gal (18.9 m^3).

The energy parameters being monitored in this building are fuel oil and electricity.



Fort Belvoir, VA
Building 508
Data Point 222
Bachelor Officers' Quarters (BOQ)

Built in 1969, this two-story, 42-person BOQ encompasses 18,360 sq ft (1706 m^2). The brick and block structure has a steel-joist-supported gypsum roof deck and built-up roofing. It is heated with oil and supplied with 216 gph (8.2 m^3/hr) of hot water. The listed capacity of its air conditioning unit is 207,000 Btuh (219 385 kJ/hr).

The energy parameters being monitored in this building are electricity, natural gas, and fuel oil.

Example 2 of "Old Barracks"

Fort Belvoir, VA
Building 1464
Data Point 228
Bachelor Enlisted Quarters (Barracks)

Built in 1958, this three-story 336-person enlisted barracks encompasses 75,034 sq ft (6971 m^2). The concrete block and brick building employs a concrete roof deck with roll composition roofing. The building is heated with fuel oil. Listed capacity of its hot water system is 1900 gal (148 m^3).

The energy parameter being monitored in this building is electricity.

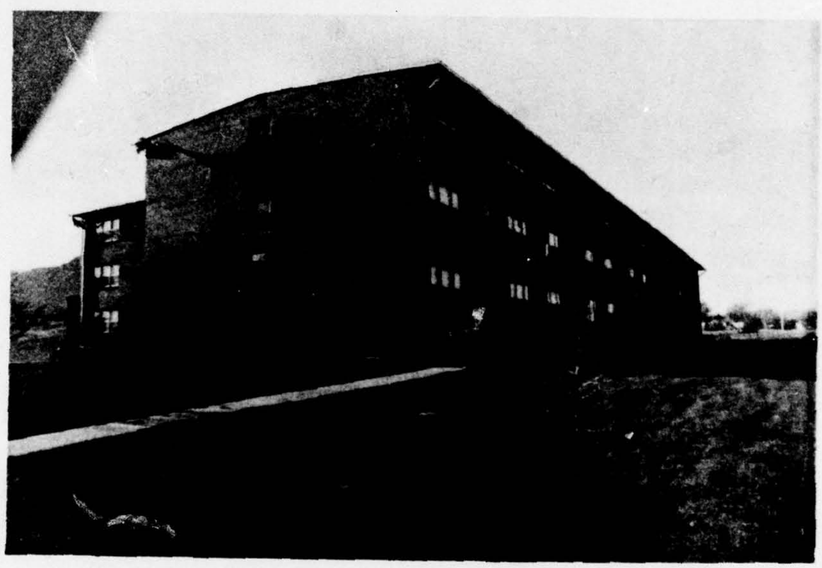
Example of "New Nonmodular Barracks"

Fort Carson, CO
Building 7304
Data Point 119
Bachelor Officers' Quarters (BOQ)

Building 7304 is a BOQ without dining facilities built in 1970. The three-story structure is composed of a primary building 238 X 42 ft (73 X 13 m) and a wing of 55.7 X 42 ft (17.0 X 13 m). The building has a total floor area of 37,100 sq ft (3447 m^2), which includes a basement mechanical room of 994 sq ft (303 m^2). The total exterior wall area is 21,905 sq ft (2035 m^2), of which 16 percent (3464 sq ft [352 m^2]) is glass. The combined U-value of the exterior wall is 0.31 Btus/°F-hr-sq ft (1.75 W/°K-m^2), and that of the roof /ceiling is 0.05 Btus/°F-hr-sq ft (0.28 W/°K-m^2).

The building is heated by a multi-loop, low-temperature, hot-water system employing baseboard radiators located along the inside perimeter. Hot water for heating is supplied by a boiler of 1.28 X 10^6 Btuh (1.35 X 10^6 kJ/hr) output capacity. Ventilation is accomplished through individual ventilation fans serving each room.

The energy parameters being monitored in this building are total electricity and natural gas.



Example of "Modular Barracks"

Fort Hood, TX
Building 87015
Data Point 335
Barracks

This 42,264-sq ft (3926 m^2), three-story enlisted barracks without dining facilities was built in 1974. The block and brick structure employs a reinforced concrete roof deck with built-up roll roofing and gravel. The building is heated and cooled with steam and cold water supplied by a central plant. The central plant supplies energy for all of the hot water.

The energy parameters being monitored in this building are electrical usage and hot and chilled water flow and supply/return temperatures.

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